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DESIGN OF ASYMMETRIC QUADRUPOLE GRADIENT BENDING R&D MAGNET FOR THE ADVANCED LIGHT SOURCE UPGRADE (ALS-U)*

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Abstract

Lawrence Bekerley National Laboratory (LBNL) is engaged in the development of magnets for the upgrade of the ALS synchrotron (ALS-U) [1]. The proposed ALS-U lattice is a 9-bend achromat reproducing the existing 12-fold symmetric ALS foot print. The ALS-U lattice requires strong focusing elements and the dipole magnet requires high gradient larger than 46 T/m. This paper presents the detailed design of the R&D dipoles under construction.

INTRODUCTION

The ALS-U lattice producing diffraction limited x ray has a 9 bend achromat [2, 3]. There are three types of main bending magnets. The first bending magnet is a relatively low gradient dipole magnet (DIPA) which is located in matching section of a sector. There are two DIPA magnets in the matching section. The second bending magnet is a high gradient dipole magnet (DIPB) utilizing a quadrupole magnet offset. Seven DIPB magnets are located in central arc section. The third bending magnet is a high dipole field super bend magnet which is only used in super bend arc sections. The superbend magnets are located in central arc section, also.

DESIGN OF R&D GRADIENT DIPOLE MAGNET

For R&D, the DIPB high gradient dipole magnet is being studied. One of ALS-U magnet design goal is that magnets should fit within ~197 m circumference of the ring. There is 75 mm space between DIPB magnet and quadrupole maget and this space is used for BPM assembly. To accomodate all the magnets in the ring, the compactness of magnets are important. For this purpose, magnet pole noses are introduced in the pole design. In this design concept, pole face to pole face length meets the physics length. Pole base and yoke are recessed from the pole tip. This additional space in beam direction is used for coil assembly so the coils do not stick out much from the magnet pole face. In this way, it saves space in beam direction and this concept is applied for other storage ring magnets. The DIPB magnet uses asymmetric quadrupole bending geometry [Fig. 1]. The magnet uses curved pole geometry which follows beam trajectory. The curved gradient dipole magnet was studied for ESRF diffraction limited light source [4].

It has C magnet yoke for radiation egress. Pole material is 27 % Cobalt iron and yoke material is 1006 steel.

MAGNETIC SIMULATION OF BASELINE R&D GRADIENT DIPOLE MAGNET

Table 1 shows the specifications for gradient dipole magnet. The requirement for the gradient field is 46.2 T/m.

Table 1: Specifications for Gradient Dipole Magnet

Parameters	DIPB	DIPC
Lattice Length	500 mm	500 mm
Nominal Bend	3.33333°	3.33333°
Reverse Bend	5.5 mrad	7.5 mrad
Total Bend	3.64846°	3.763052°
Number in Sector	2	5

Figure 1 shows magnetic field simulation of baseline R&D gradient dipole magnet. For the simulation, Vector Field Opera software is used. Pole tip radius for the asymmetric R&D quad-bend is 19.5 mm and to generate high gradient (46.2 T/m), 7010 Amp-turns of current is needed for the coils. To obtain effective dipole field (7762 G), the magnet is shifted in x direction. The offset value in x direction is 16.09 mm which means the beam is located at x = -16.09 mm. The magnetic field efficiency for the baseline magnet is 97.4 %.

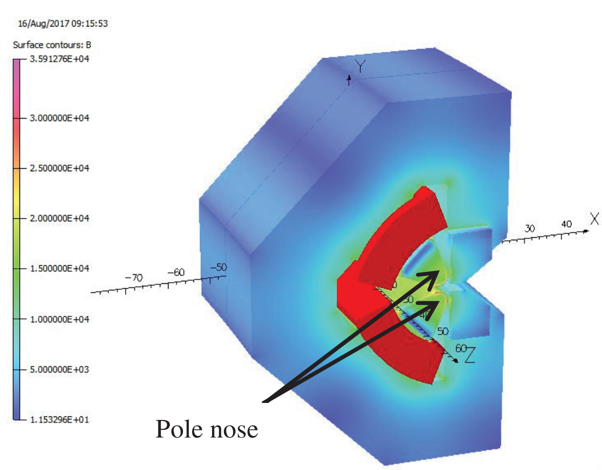

Figure 1: Magnetic Field Simulation.

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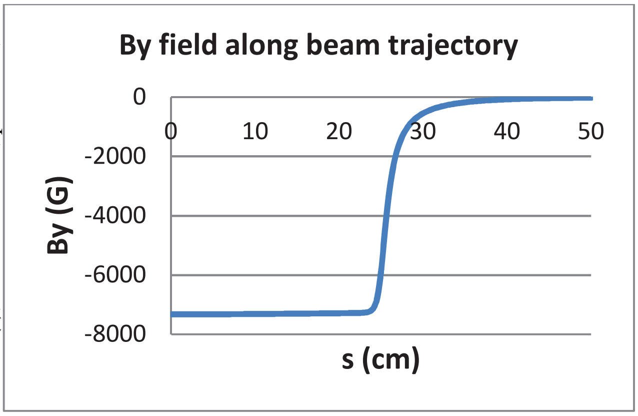

Figure 2: By Field along Beam Trajectory.

Figure 2 shows By field along beam trajectory for the baseline magnet. Since it is not saturated (97.4 % effi-ciency), By field within the magnet region shows flat pattern.

Table 2 shows effective multipoles for the baseline asymmetric quad-bend magnet. Effective multipoles are calculated based on multipole integration along beam trajectory and multipoles are calculated at the radius of 5 mm with respect to x = - 16.09 mm. Effective dipole (7766 G) and quadrupole field (2309.5 G => 46.2 T/m) meets the requirement. Due to the asymmetric feature, there is about 10 G of sextupole and 8 G of octupole.

Table 2: Effective Multipoles

n	A_n (G)	B_n (G)	C_n (G)
1	0	-7766.04	7766.04
2	8.52E-10	2309.53	2309.53
3	1.39E-09	-10.11	10.11
4	1.59E-09	-7.72	7.72
5	1.17E-09	-0.61	0.61
6	5.21E-10	-0.66	0.66

Vector Field Opera uses following equations for the calculation of multipoles.

Magnetic field equation

$$By + iBx = B_{main} \sum (b_n - ia_n)(\frac{z}{r})^{(n-1)}$$

Expansion of magnetic field used in Vector Field Opera

$$A_z = \sum a_n^n \sin(n\theta) + b_n^n \cos(n\theta)$$

Coefficients used in Vector Field

$$A\_n = a_n^n, B\_n = b_n^n, C\_n = (A\_n^2 + B\_n^2)^{0.5}$$

MAGNETIC SIMULATION WITH CHANGING GRADIENT FIELD

By physics requirement, the availability of +/- 5 % of quadrupole gradient field change is needed while keeping the dipole field same as baseline dipole field. This requires additional dipole trim coils to control dipole field and quadrupole gradient. Fig ure 3 shows magnetic field simulation for quad-bend with dipole trim coil for 5% higher quadrupole gradient keeping dipole field same as baseline field.

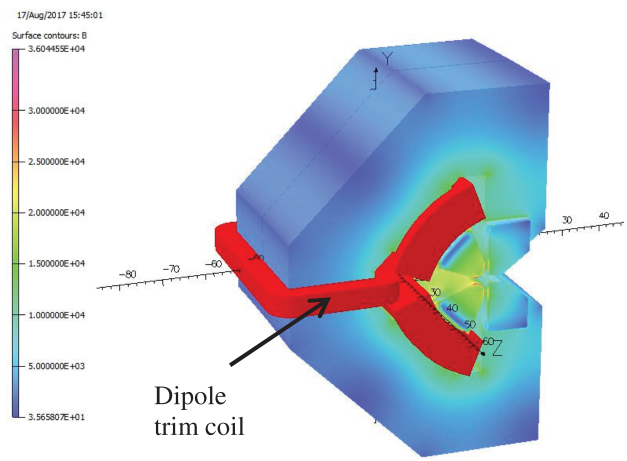

Figure 3: Magnetic Field with Dipole Trim Coil.

To achieve the field requirements, quadrupole coil current and dipole trim current are iteratively determined. The current values are 7819 Amp-turns for quadrupole coil and 1337 Amp-turns for dipole trim coil.

Table 3: Effective Multipoles for 5% Higher Gradient

n	A_n (G)	B_n (G)	C_n (G)
1	0	-7762.73	7762.73
2	-1.71E-10	2423.09	2423.09
3	-3.41E-10	24.97	24.97
4	-3.07E-10	-2.63	2.63
5	-3.06E-10	-1.24	1.24
6	-6.80E-11	-0.84	0.84

As can be seen in the Table 3, quadrupole field (2423.09 G) is increased by 5% from baseline field (2309.53 G) while keeping the dipole field as nominal field. Using dipole trim coil, about 35 G of sextupole field is generated comparing Table 2. The total sextupole field (25 G) is well within the physics requirement (+/-200 G).

There is another requirement for the gradient field value which is 5% lower gradient than the baseline value. To achieve these conditions, quadrupole coil current and dipole trim coil current are iteratively determined again. Table 4 shows this case. In this case, 6210 Amp-turns are

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used for quadrupole coil and -1353 Amp-turns are used for dipole coil.

Table 4: Effective Multipoles for 5% Lower Gradient

n	A_n (G)	B_n (G)	C_n (G)
1	0	-7762.91	7762.91
2	1.89E-09	2192.53	2192.53
3	3.14E-09	-45.68	45.68
4	3.51E-09	-12.88	12.88
5	2.66E-09	0.05	0.05
6	1.12E-09	-0.48	0.47

As shown in the Table 4, quadrupole field (2192.53 G) is decreased by 5% from baseline field (2309.53 G) while keeping the dipole field value. Using dipole trim coil, the total sextupole field is -46 G and it is about -35 G of sextupole field change comparing Table 2.

STRUCTURAL CALCULATION FOR QUAD-BEND MAGNET

Pole deformation by magnetic force makes magnetic field strength changes. So, it is important to minimize the magnet deformation. Since the magnetic forces are high for the case of 5% higher gradient. Structural calculation is done for the case.

Figure 4 shows structural analysis of the magnet with 5% higher gradient field. For the analysis, all of magnetic forces are applied on pole face and field retrun yoke face. It is estimated that the total deformations on quad poles are about 10 µm and the total deformations on field return yoke are about 14 µm.

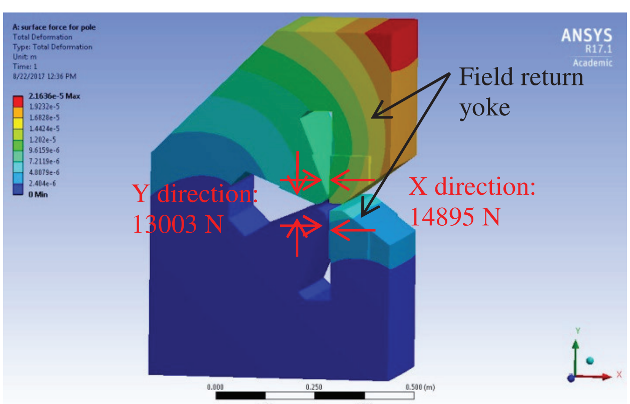

Figure 4: Structural Calculation with + 5% Gradient.

MECHANICAL DESIGN OF R&D QUAD-BEND MAGNET

Figure 5 shows a mechanical design for R&D quad-bend magnet. The region of cobalt iron pole is optimized to reduce the amount of material for cost reduction. Poles are detachable from the yoke to assembly quadrupole coil pack and field return yokes are bolted to the main yoke assembly. The main yoke has detachable top and bottom assemblies to install dipole trim coil.

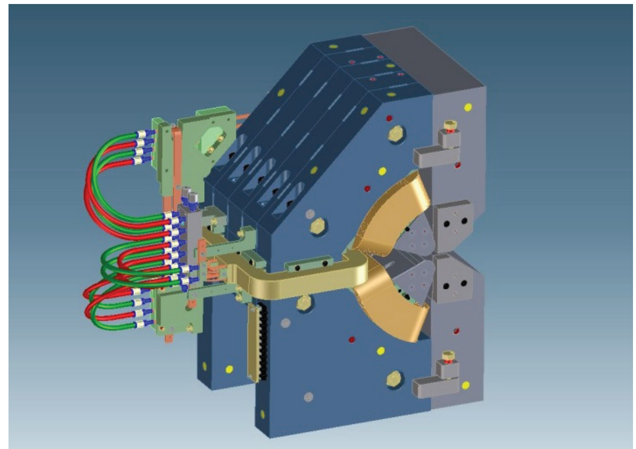

Figure 5: Mechanical Design.

CONCLUSION

Magnetic field calculation methods have been developed to meet the physics requirement for dipole field and quadrupole field. Introducing pole nose design, pole and yoke geometry are developed such that the magnet is space efficient in beam direction. It is demonstrated that +/- 5% gradient field change can be implemented with acceptable multipole contents. Mechanical analysis is performed to understand deformations under energized magnet. Based on structural analysis, thickness of yoke is determined to reduce magnet deformation under magnetic forces.

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