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PERMANENT DIPOLE MAGNET R&D FOR SPring-8-II

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Abstract

Permanent magnets are promising components for future light sources in point of small electric power consumption, compactness and so on. We have proposed a variable-field permanent dipole magnet and demonstrated its performance. Following the result, a prototype magnet with a longitudinal field gradient and a magnetic shunt circuit was designed. The longitudinal field gradient dipole enables a lower beam emittance and a magnetic shunt circuit improves a temperature stability of the magnetic field strength. In this paper, simulation results for this magnet are presented. The interference with magnetic fields of neighboring magnets was also investigated.

INTRODUCTION

SPring-8-II is an upgrade project of SPring-8 and a very-low emittance storage ring with a high-packing-factor lattice has been studied [1]. As a dipole magnet system of the SPring-8-II, we plan to adopt permanent dipole magnets. Permanent magnets have advantages over electromagnets in terms of electric power consumption, stability and reliability because no power supply and no cooling system are necessary.

The proposed five-bend lattice of SPring-8-II is composed of a normal bending magnet (NB) at the center of the cell and four other bending magnets with longitudinal field gradient (LGB) as shown in Fig. 1.

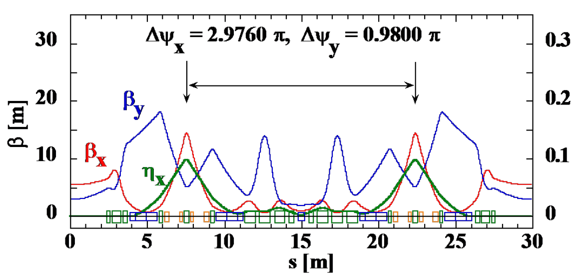

Figure 1: A unit cell of the 5-bend achromat optics for SPring-8-II.

LGB is divided into three segments and the strength of each segment is optimized to achieve a half of the emittance value with a conventional homogeneous dipole field. The major specifications of bending magnets are listed in Table 1.

We started R&D for permanent magnet dipole in 2013 and fabricated a sector magnet to verify fundamental performances [2]. Following this study, we have started a more specific design of LGB including an optimization of outer plates, magnetic shunts, field distributions, mechanical structures and so on.

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Table 1: Major specifications of permanent bending magnets.

Magnetic field [T] NB / 2 types of LGB	0.953 / 0.166, 0.296, 0.582 0.221, 0.395, 0.775
Effective length [m] NB / LGB	0.42 / 0.7, 0.7, 0.35
Gap [mm]	25
GFR [mm]	±12
Field error	5×10^{-4}

LONGITUDINAL GRADIENT BEND WITH OUTER PLATE

It is required to adjust magnetic field strength within a tolerable range after the fabrication, and possibly to change it in a relatively large range when the operating energy of an accelerator needs to be changed. In order to satisfy these requirements, we proposed a variable-field magnet with outer plates where the flux is intentionally leaked so that the magnetic field that beam experiences can be adjusted by moving the outer plates [2].

A configuration of LGB is shown in Fig. 2. Three outer plates are located above and below the main circuit where magnetic fluxes are leaked. A magnetic field strength of three magnets can be adjusted independently by changing the distance between the outer plate and the main circuit.

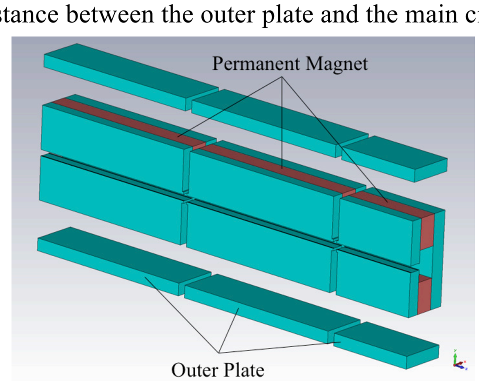

Figure 2: Longitudinal gradient bend with outer plates.

Fig. 3 shows a simulated longitudinal distribution of the magnetic field strength in an LGB for outer plate positions of 0 and 100 mm, respectively. We used CST STUDIO [3] for the magnetic field simulation. The magnetic field can be decreased below 30 percent of maximum strength at the closest position of the outer plate. A size, and a horizontal position of the outer plate will be optimized considering a tunable range and position sensitivity for the magnetic field. Alternative configurations have also been discussed such that

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permanent magnets are placed in a return yoke for reducing the number of outer plates. The varieties of designs are not shown, though.

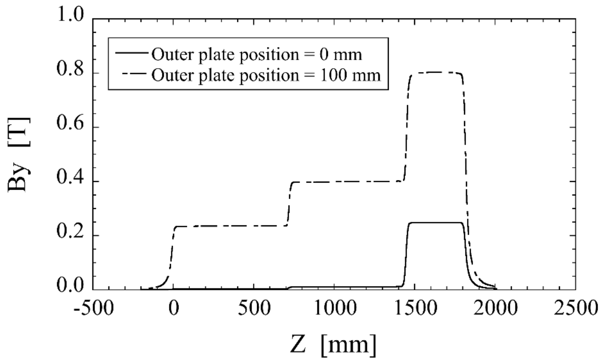

Figure 3: Simulated longitudinal field distributions for outer plate position at 0mm and 100mm.

PROTOTYPE MAGNET FOR LGB

Specifications

In order to confirm fundamental performances such as field strengths, field distributions, temperature stability, mechanical accuracy, deformation due to magnetic force and so on, we designed a prototype LGB. Major parameters of this magnet are summarized in Table 2.

Table 2: Major Specifications of Prototype LGB

Magnetic field [T]	0.13, 0.23, 0.45
Pole length [mm]	100, 100, 100
Inter-pole space [mm]	30
Gap [mm]	25
Nose length, height [mm]	7, 10

The prototype magnet consists of Neodymium permanent magnet (NEOMAX®: NMX-33UH), iron pole and yoke (SS400), and Fe-Ni alloy for magnetic shunt (NEOMAX®: MS-2).

Nose Structure

LGB consists of three magnets with different field strengths. These magnets are located with some spaces between them considering the balance of magnetic couplings (cross-talks) and field dips in the inter-pole space. In order to compensate the field dip sustaining a relatively small cross-talk (large inter-pole space), we adopt nose structures at the pole edges facing to another pole as shown in Fig. 4.

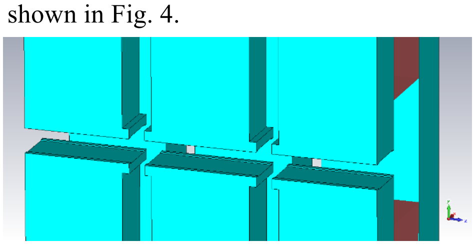

Figure 4: Nose structure for compensation of field dip between LGB poles.

The size of nose structures was optimized considering not only the dip compensation but also the field saturation in the nose. Fig. 5 shows a result for the optimization.

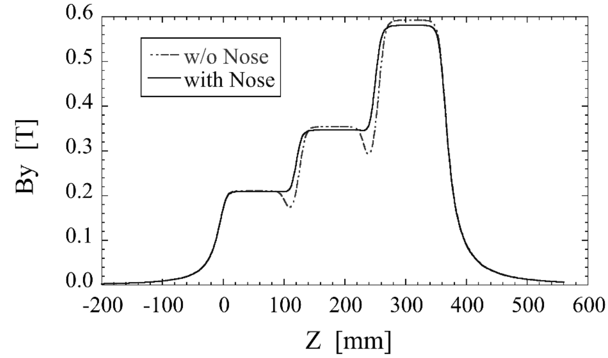

Figure 5: Compensation of field dip between LGB poles using nose structures.

Magnetic Shunt Circuit

The remanence of permanent magnets depends on its temperature. For example, the temperature coefficient of NMX-33UH is -0.09 %/K and it causes unacceptable change in beam performance, especially an electron energy, in case the temperature of ambient air in an accelerator tunnel shifts. In order to cure this problem, a magnetic shunt circuit is adopted. In a magnetic shunt circuit, a piece of magnetic alloy with a large temperature coefficient is placed in parallel with the main circuit and a portion of the magnetic flux pass through in the shunt alloy. Since the flux change of the shunt alloy due to the temperature fluctuation is larger than that of the permanent magnet, the flux change of the main circuit is relatively reduced. The fraction of the shunt flux is chosen so that the flux at the pole gap is kept in constant. The magnetic field distribution in a prototype LGB with a magnetic shunt is shown in Fig. 6.

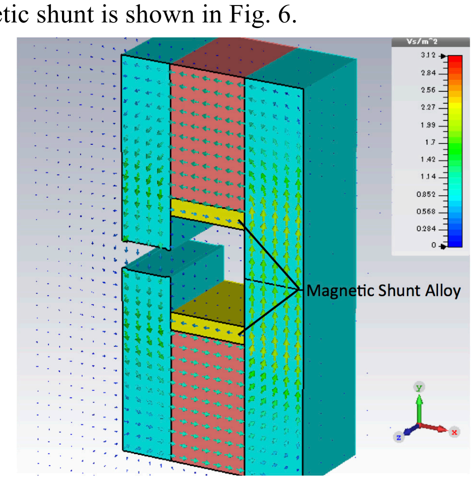

Figure 6: Magnetic field distribution in a prototype LGB with a magnetic shunt.

The thickness of the magnetic shunt alloy (MS-2) was optimized using measured B-H curves (H < 800 A/m) for the temperature of 20 and 30 degree Celsius. Fig. 7 shows the optimization result for the thickness of MS-2. The temperature coefficient for the gap field can be zero with

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a thickness of 17.7 mm where the coercivity in the MS-2 becomes in the range between 50,000 to 110,000 A/m. We plan to measure the B-H curve for MS-2 in a coercivity range of up to 400,000 A/m to refine the simulation.

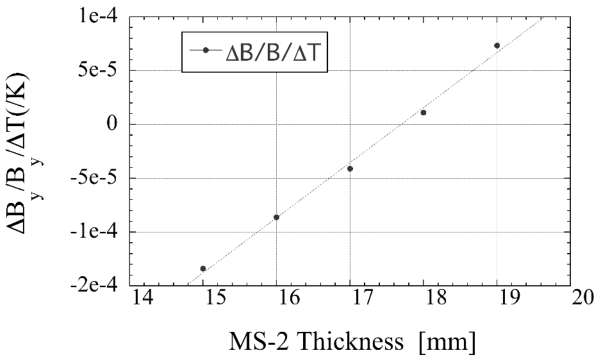

Figure 7: Simulated optimization for the thickness of a magnetic shunt material for the prototype LGB.

Mechanical Structure

Each segment of the prototype LGB is assembled with aluminium end plates with a thickness of 10 mm. The target accuracy of the pole gap is within ±50 μm. Deformation due to the magnetic force was simulated by ANSYS. The attracting force of the pole gap for the highest field (0.45T) magnet is 431 N and the amount of the maximum deformation is 3.0 μm as shown in Fig. 8.

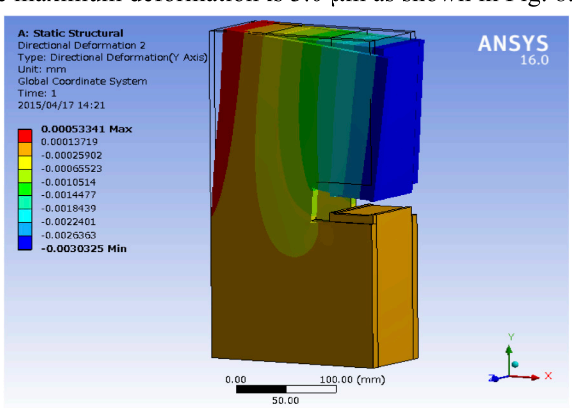

Figure 8: Deformation of a prototype LGB.

FRINGE FIELD

The fringe field in the longitudinal direction produces undesired field at neighbor magnets such as a quadrupole magnet. In the present design of the SPring-8-II optics, the nearest magnet from LGB is a quadrupole with a maximum field gradient of 56 T/m and their distance is in a range from 120 to 350 mm. Fig. 9 shows a magnetic field distribution in a shielding plate and longitudinal distributions of a fringe field for a drift space of 120 mm. In a case of a free space i.e. without quadrupole and shielding plate, the magnetic field strength at a position of 120 mm is about 60 Gauss and its direction is vertical. It decreases to 5.2 Gauss in a case that a quadrupole magnet is located, because most of the absorbed magnetic flux bypasses in return yokes of a quadrupole. This residual field corresponds to a shift of magnetic center by 9 μm in a horizontal direction for a quadrupole with a field gradient of 56 T/m. Furthermore, it can be reduced to a comparable level with a geomagnetic strength as necessary if a proper shielding plate is installed between an LGB and a quadrupole.

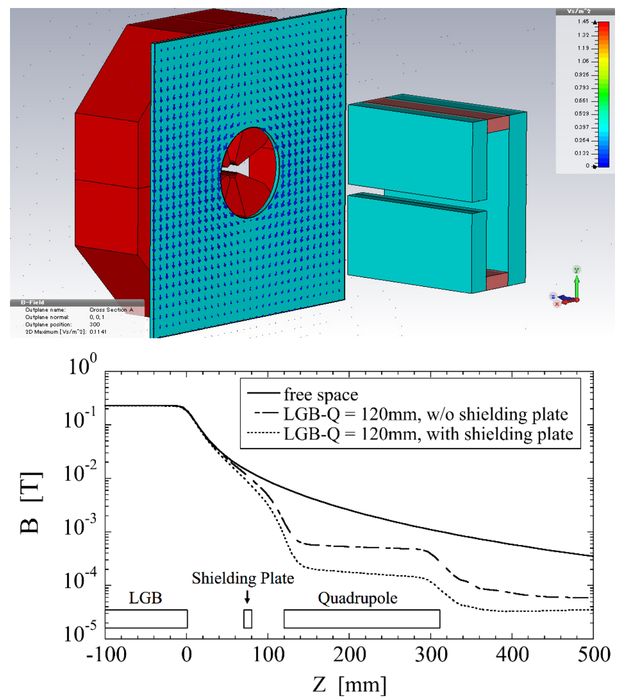

Figure 9: Magnetic field distribution in a shielding plate (above) and that on a beam axis (below).

CONCLUSION

Dipole magnets using permanent magnet have been investigated for SPring-8-II. Outer plates enable variable field strength and a nose structure compensates a field dip between magnet poles of LGB. Fringe fields at a neighbour quadrupole magnet were estimated and it could be suppressed sufficiently low with a shielding plate. A prototype LGB was designed to confirm fundamental functions of LGB and it is under fabrication. We will design a realistic model of LGB and normal bend through kinds of measurement for this prototype.

ACKNOWLEDGMENT

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