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STEERING MAGNETS WITH PERMANENT MAGNETS

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Abstract

Steering magnets with permanent magnets are investigated. They need to generate both polarities of magnetic fields, which can be realized by rotating permanent magnet rods. Such a magnet system will reduce not only electricity but also maintenance cost. The structure and the field adjustment scheme of a trial conceptual design will be discussed.

INTRODUCTION

Electromagnets, which are widely used as optics elements for beam handling, may be replaced by permanent magnets. In addition to reductions of the electricity for coil excitation and cooling, thick electric cabling and water piping, power supply and their maintenance costdown are also expected. Among optics elements, steering magnets need to generate bipolar magnetic fields, which can be realized by rotating permanent magnet rods [1].

One demand for such a device comes from Ring To Main Linac (RTML) beam lines, whose lengths are more than that of the main linac. Another demand comes from ILC Damping Ring (DR), where more than 300 steering magnets will be installed for orbit correction [2]. With permanent magnets, there is no DC power supplies, no cooling water, and then these failures will never happen. Water leaks have been annoying events among maintenance activities, which would also be dramatically reduced if permanent magnets were applied. These items offer cost reductions for both construction and operations.

While many advantages are expected, we need some investigations in applying permanent magnets. At least three subjects have to be considered: temperature dependence of remnant field (Br), adjustability and demagnetization caused by radiation. The temperature coefficient can be compensated by magnetic shunts made of magnetic materials with low Curie temperature, which have large temperature coefficient around their operating temperatures [3]. Although the strength adjustment of magnets made of permanent magnets are not easy compared with electromagnets, there are some methods that can be incorporated. In order to change the magnetic flux density generated in a gap, we rotate permanent magnets in the structure, which enables a bipolar operation and is suitable for correction magnets. The rotating mechanism may also have troubles like a failure of power supply for electromagnet. The permanent magnet system, however, will not lose the deflecting strength but just the adjustability from the current position, which will not prevent the machine operation immediately, since the adjustment is not expected to be so often in a daily operation.

CORRECTION MAGNET

Assumed magnet length and beam pipe diameter are about 32 cm and 6 cm, respectively. Eight ferrite permanent magnet rods with about ø50mm diameter can generate enough strength. We assume to use Y30H, whose remnant field Br is about 0.4T. The magnet diameter is chosen from an available magnet ingot size (25.4×100×150 mm). The octagon shaped magnet rod has a slightly larger volume than a cylindrical rod that can be machined from the ingot with the same size. Figure 1 shows a possible bipolar correction magnet, where the magnet rods are rotated by a stepping motor to vary the magnetic field strength (see Fig. 2). The adjacent rods rotate with opposite directions each other so that the mag-

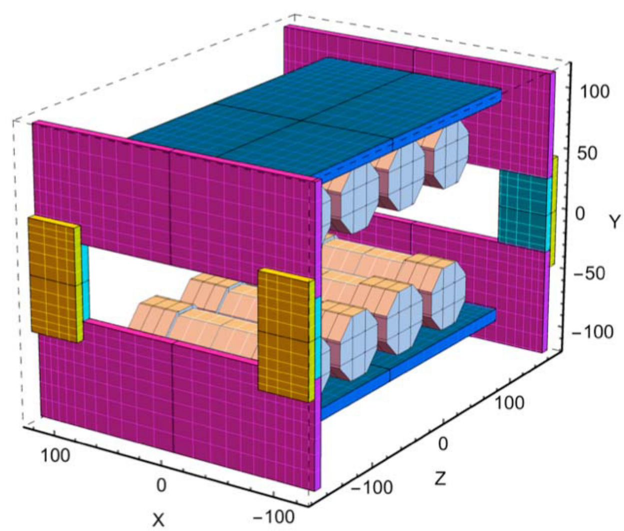

Figure 1: Outline of the permanent steering magnet.

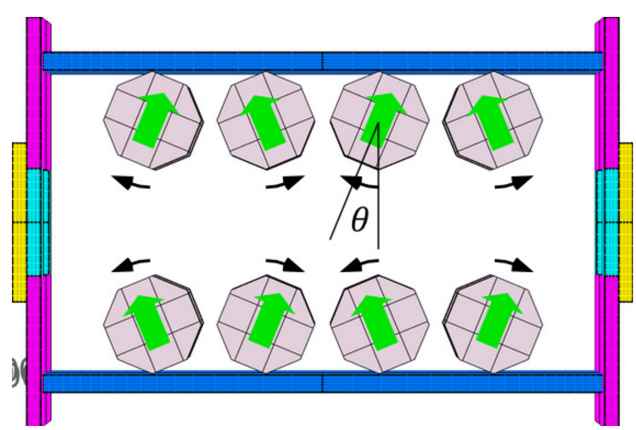

Figure 2: Cut view of the permanent steering magnet. The magnet rods rotate oppositely each other.

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netic field is perpendicular to the median plane and the integrated magnetic field along the axis (so called BL product) can be cancelled out in a short period, which minimizes a beam shift. Figure 3 shows the schematic flux plot for three rotation angles calculated by PANDIRA. When the rotation angle is zero, easy axes of the rods are aligned. The rod rotation makes the part of the magnetic field on the axis cancel each other.

For realistic analysis, 3D calculations with RADIA 4.31 4 were carried out based on the geometry as shown in Fig. 1. In order to achieve a better flatness of the magnetic field, the center part of the magnet rod is modified. The width and the radius at the center are adjusted so that the multipole components other than the dipole component around the beam axis become small. Figure 4 shows two lines where the sextupole or decapole component becomes zero when the width and the radius of the middle part of the magnet rods are changed. The crossing point of these two lines satisfies the condition that both the multipole components become zero in this configuration.

The resulted magnetic field map on the median plane is shown in Fig. 5 at the rotation angle of zero. Figure 6 shows the calculated By distributions along the beam lines of X=0, 10 and 20 mm at the rotation angle of zero in this geometry. Because the field flatness is well optimized, all there lines are overlapped in this figure. Owing to the Maxwell equation, vertical variation should show the similar magnitude.

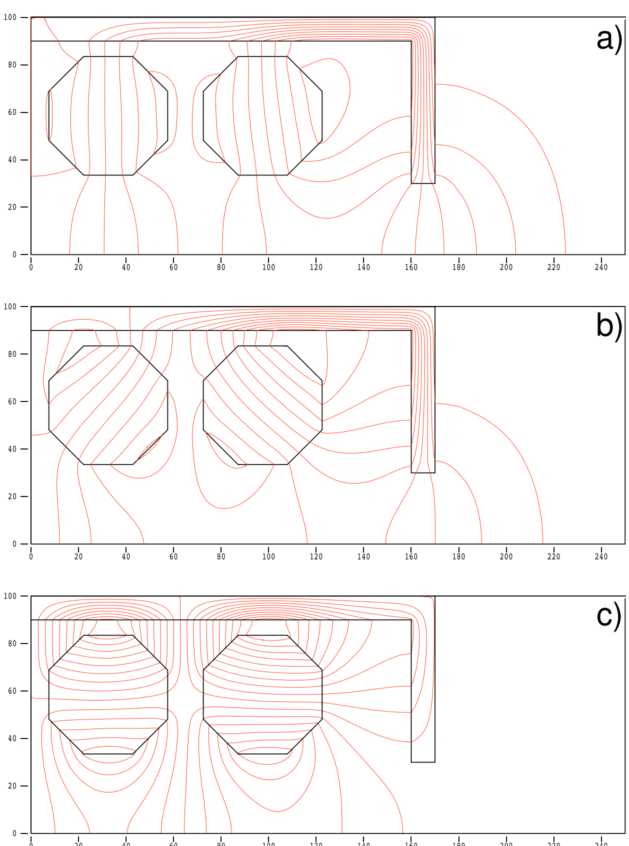

Figure 3: Schematic flux plots for three rotation angles. a) θ=0º, b) θ=45º, c) θ=90º.

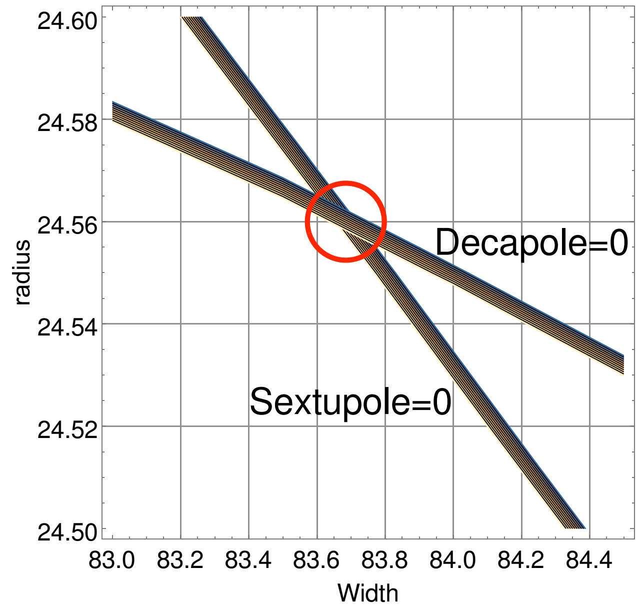

Figure 4: The lines where the sextupole or decapole components becomes zero when the width and the radius of the middle part of the magnet rods are changed. The radius refers to facing corner to corner distance in here. The crossing point of these two lines satisfies the condition that both the multipole components become zero.

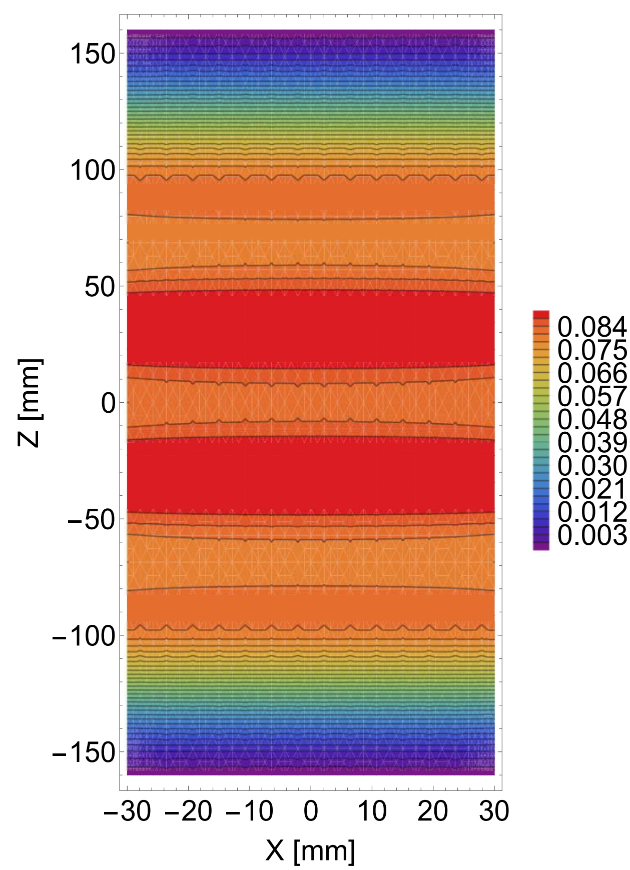

Figure 5: Magnetic field (By [T]) map on the median plane along the full span in Z direction. Fairly flat magnetic field distribution is achieved.

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Figure 7 also shows the calculated By distributions along the beam line at X=0, but for the rotation angles of 0°, 45°, 90°, 135° and 180°. The reflection symmetry of the field distributions at 0° and 180° should show the consistency in the calculation. The distribution changes with the rotation angle and then the BL product changes. The BL product value based on this calculation is shown in Fig. 7. As can be seen, the BL product changes sinusoidally with the rotation angle. Because the field flatness is well achieved, the higher multipole components are fairly small and the extracted values may not be precise. This may be the reason why some calculated points in Fig. 8 show discontinuities on their curves. In spite of the possible numerical errors in the multipole components, they grow when the permanent magnet rods are rotated, while the values at zero angle is well suppressed. These components tend to become large when the main dipole component becomes small, which results large relative error. If these values are not acceptable for beam dynamics, compensation techniques would be needed such as putting tiny correction magnets on the rods.

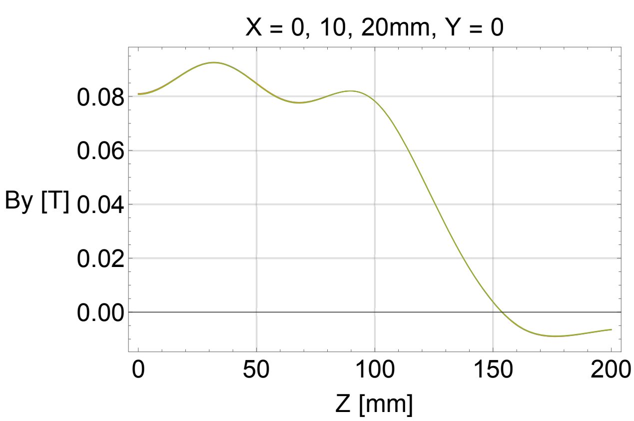

Figure 6: Magnetic field (By [T]) distribution along beam at X=0, 10 and 20 mm positions. Because of the well-optimized geometry, all three lines are overlapped in this figure.

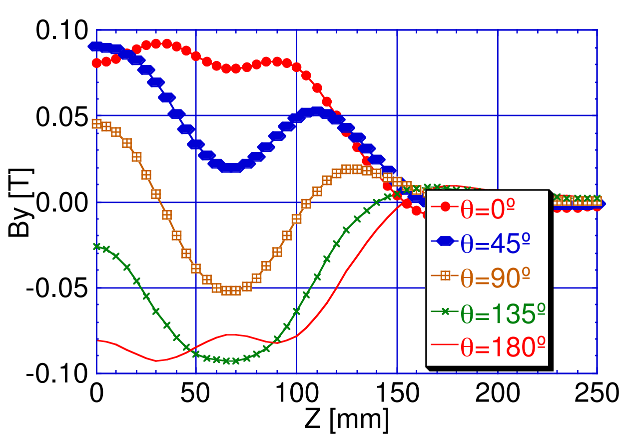

Figure 7: Magnetic field (By [T]) along beam line. The distribution changes with the rotation angle.

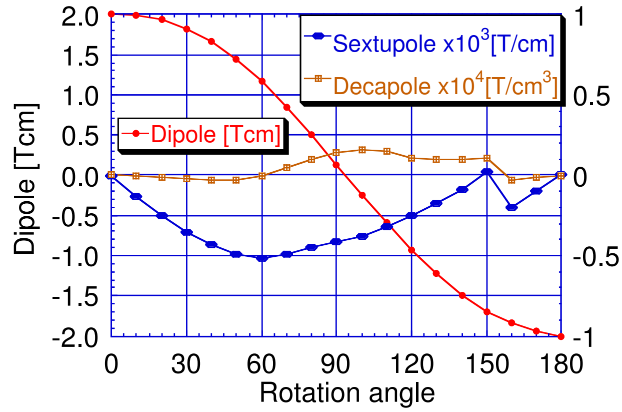

Figure 8: BL product as a function of rotor angle. Multipole components are also shown.

CONCLUSION

While some studies on PM dipoles as unipolar dipoles have been reported [5, 6], a permanent magnet system with bipolar adjustability is under investigation. Permanent magnets have a possibility to reduce the fabrication cost in addition to the operation and maintenance cost. A conceptual design of the magnet is proposed using less expensive ferrite magnet compared with strong rare earth magnets. Magnetic field adjustability for the correction magnet can be realized by rotation of magnet rods, which vary the magnetic field distribution. Reduction of the higher multipole components during rotation has to be investigated. Temperature dependence of the magnet material can be cancelled by shunt circuits with special magnetic material and/or the adjustability function. The study on the demagnetization caused by radiation of ferrite magnets is planned.

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