PERMANENT MAGNET QUADRUPOLE LENS WITH VARIABLE STRENGTH

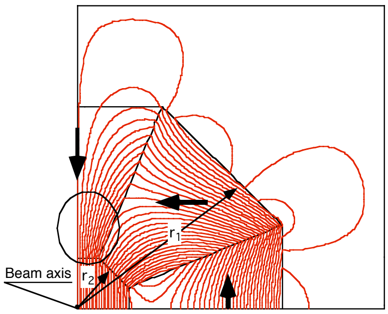
Y. Iwashita, Kyoto University, Kyoto, Japan
M. Kumada, NIRS, Chiba, Japan

Abstract

The field strength generated by permanent magnets has been further extended by introduction of saturated iron. Such permanent magnet quadrupole lens is one of the candidates for the final focus lens for a Linear Collider System, because of its compactness and less power consumption, while one drawback is its fixed strength. One remedy is proposed to change the total strength of the lens by rotating divided pieces separately. The mechanical scheme will be discussed.

1 INTRODUCTION

Strong magnets made of rare earth permanent magnet material were proposed by K. Halbach[1]. Fig. 1shows a standard configuration for a dipole magnet. When we take a look at the bottom region of the top magnet, which is made by an ellipse, the operating point is located deep in the first quadrant of the B-H curve (see Fig. 2). At the same excitation level, usual soft iron material can generate higher magnetic field strength than the permanent magnet. Thus one can enhance the field strength with substituting such area by soft iron material (see Fig. 3). Fig. 4 shows the permanent magnet dipole, which generates 4.45 T at –29°C and 3.9T at room temperature[2,3,4,5].



1.37 T @r_1, r_2=1cm, 4cm

Fig. 1 Halback's dipole magnet.

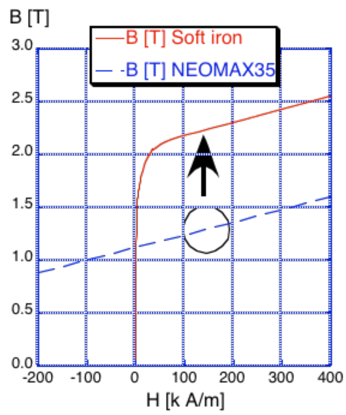
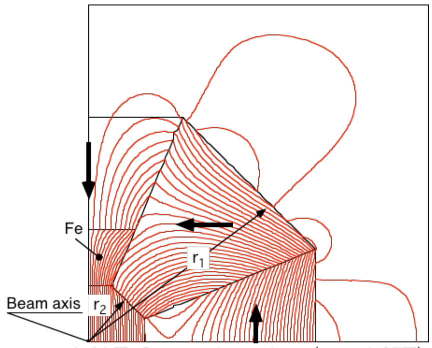


Fig. 2 B-H curves for permanent magnet and soft iron.



1.64 T @r_1, r_2=1cm, 4cm (was 1.37T)

Fig. 3 Modified Halbach's magnet.

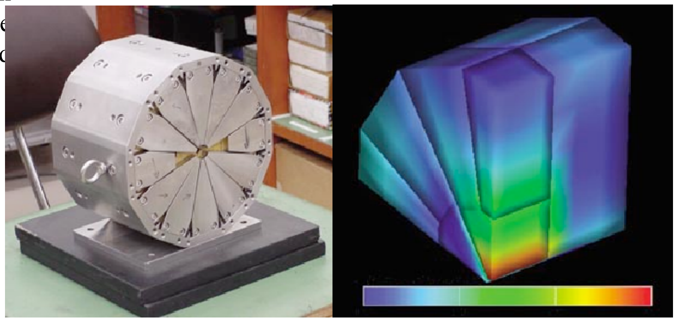


Fig. 4 4.45T magnet (at –29°C). The magnetic field at room temperature is 3.9T.

2 SATURATED IRON PMQ

Similar technique can be applied for a permanent quadrupole magnet (PMQ). Fig. 5 shows an example of a saturated iron permanent quadrupole magnet (iPMQ). The

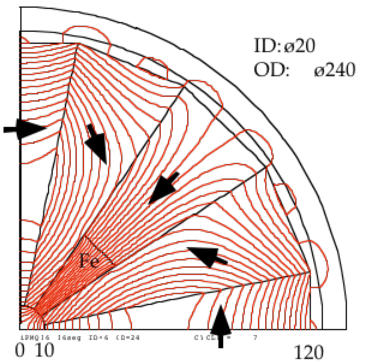


Fig. 5 Saturated iron permanent quadrupole magnet.

magnetic field gradient increases from 2.2T/cm to 2.4T/cm with the saturated iron piece (see Fig. 6). It can further go up to 2.5T/cm with higher magnetic field saturation material such as permendur.

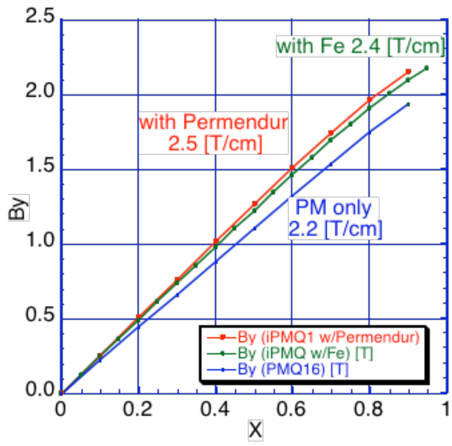


Fig. 6 Magnetic field distribution in permanent magnet quadrupoles.

3 FINAL FOCUS SYSTEM

Fig. 7 shows a rough overview of a linear collider. Because the beams have to be strongly focused at the interaction point, we need strong focusing lenses. It should be noted that the focusing system has to manage not only incoming beam but also outgoing beam. There are three options for the magnets: superconducting magnet, normal conducting magnet and permanent magnet. In the first option, the outgoing beam can fit in a large aperture that can be only realized by superconducting magnets. In normal conducting electromagnet case, the beam can go through the vacant space between iron poles. Because PMQs can be small in size, the beam can go through outside of the PMQ. In this case, larger crossing angle between the two beams is preferred. The distance between the two beams depends on the crossing angle between them, which seems not have a definite number for the time being. For 8 mrad crossing angle and 2m location, the leaving beam is located at 16mm off the axis and can have up to ø32mm diameter, which should be reduced by the margin of the leaving beam size(see Fig. 9). Because the length of the magnet is about 2m, the diameter at the end is twice in the size.

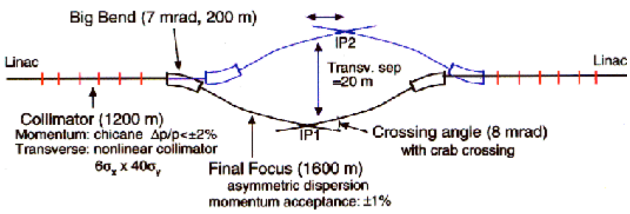


Fig. 7 Rough overview of a linear collider.

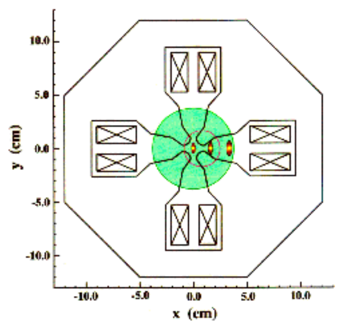


Fig. 8 Outgoing beam can go through the vacant space between iron poles.

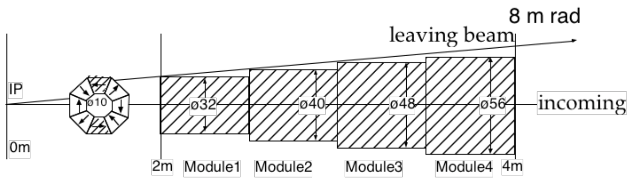


Fig. 9 Final focus magnet made of PMQ.

4 TUNABILITY

Because the size of a primary block of a permanent magnet is up to 10 cm, such a long magnet has to be assembled from many short units. Field gradient in a quadrupole magnet changes its sign by 90° rotation around its axis; the focus magnet turns to defocus magnet. By rotating the short units, the total focal strength can be changed with a resolution specified by the unit size. Although this scheme is stepwise, it does not introduce skew component in the magnetic field, while the precision of the rotation does matter.

Suppose that 1cm unit out of 2m is flipped, the focal strength is decreased 1% and thus the resolution is 1%. Because the centroid of the lens changes with the distribution of the flipped units, the distribution is another parameter to adjust the strength.

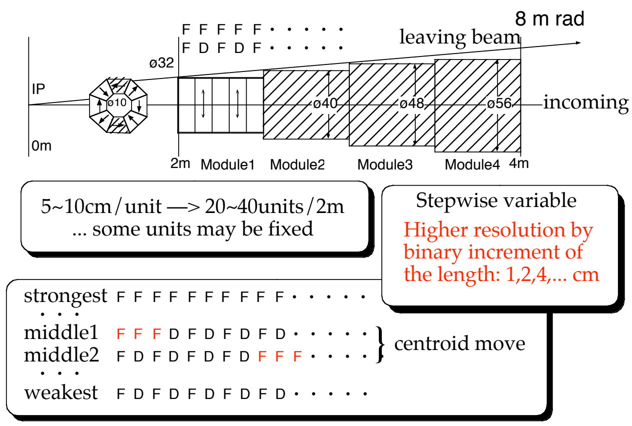


Fig. 10 Stepwise adjustment of the focal strength

5 Q-MAGNET

The PMQ with smaller diameter has smaller field gradient. If we need stronger magnets or the crossing angle becomes small, the outgoing beam penetrates the magnet. In order to leave a space for the outgoing beam, magnet material has to be removed (see Fig. 11). Although the gradient decreases with the magnet material removal (xPMQ2), the saturated iron scheme recovers or overcomes the reduction (ixPMQ).

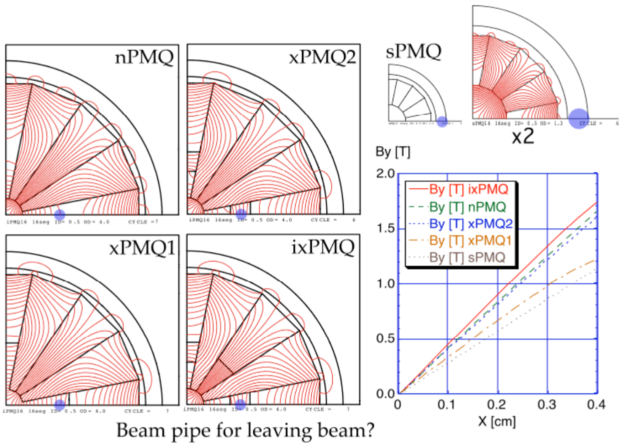


Fig. 11 Holes in PMQs for leaving beam.

6 TEMPERATURE COMPENSATION

Photons are emitted from the beams when they are bent. Because the permanent magnets has somewhat larger temperature coefficient and there might be anisotropic temperature rise caused by the photon irradiation, the magnet center may move. This effect may be canceled with a combination of two permanent materials (see Fig. 12), although the total focal strength reduces to 60%. This kind of technique has to be incorporated combined with an optics design.

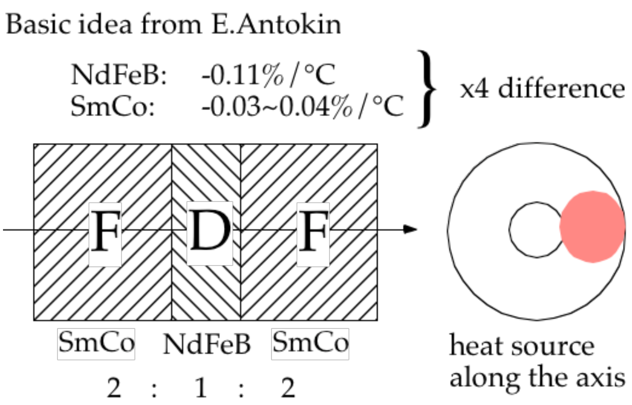


Fig. 12 A temperature coefficient compensation scheme.

7 SOME ISSUES

Preliminary simulation results show upper limits for tolerances:

1) tolerance in strength is up to 10^{-5},
2) tolerance in rotation is up to 3 μrad,
3) tolerance in magnet center displacement is up to 0.2nm,
4) temperature coefficient has to be compensation to reduce the displacement of the magnet center,
5) radiation damage of the magnet material has to be considered, and
6) step size can be up to 1% with magnet movement along the axis.

First three are so tight that they need feed back compensation from the beam. The displacements has to be relocated by piezo actuators with feedbacks from the beam. Fig. 13 and Fig. 14 show the horizontal and vertical stages, respectively, which are commercially available[6]. Rest of the issues need investigations in detail.

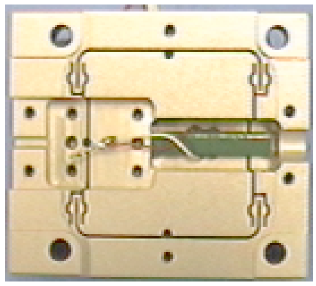


Fig. 13 Horizontal stage.

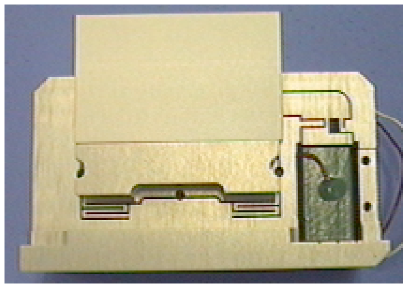


Fig. 14 Vertical stage.

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