PERMANENT MAGNET QUADRUPOLE FOR FINAL FOCUS FOR LINEAR COLLIDER

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Abstract

Strong Permanent Magnet Quadrupole Lens is one of the candidates as the final focus lens for the linear collider, because of its compactness and less power consumption, while one drawback is its fixed strength. The total strength of a lens can be changed by rotating subdivided pieces separately. Some issues on such a system will be discussed.

INTRODUCTION

High magnetic field generation as high as 4.45T has been demonstrated without superconducting technology. It is based on the modified Halbach's configuration [1,2,3,4], which introduces saturated iron poles to the original configuration to enhance the magnetic field strength[5,6,7]. This situation is explained in Fig. 1, whose left figure shows the original Halbach's configuration. The operating point of the circled region in the figure is far in the first quadrant in B-H curve (see right figure in Fig. 1). Even plain soft iron can generate higher magnetic flux density than any known permanent at such operating point. By replacing permanent magnet material in the region with soft iron, the magnetic field density increases even with such simple case (see Fig. 2). One can optimize the dimensions to obtain more effect from this technique. Fig. 3 shows the fabricated magnet that has achieved the 4.45T magnetic flux density and the calculated field density. The magnetic flux density is expected to become higher when we cool down it more.

Same technique can be applied to a quadrupole magnet and can generate higher magnetic field gradient than a plain electromagnet. This feature may have advantage in the linear collider field since it needs rather stronger magnetic filed gradient. A structure of a test quadrupole magnet using the saturated iron is reported in this paper. The measured data is also presented.

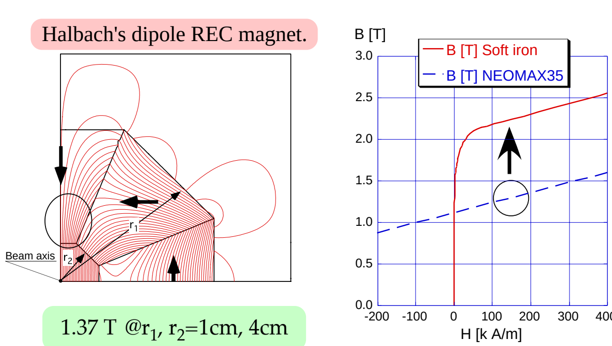

Fig. 1 Left: original Halback's configuration can generate 1.37T in the bore. Right: The operating point of the region marked by the circle in the left figure is far in the first quadrant of the B-H curve, where plain soft iron is stronger than permanent magnet.

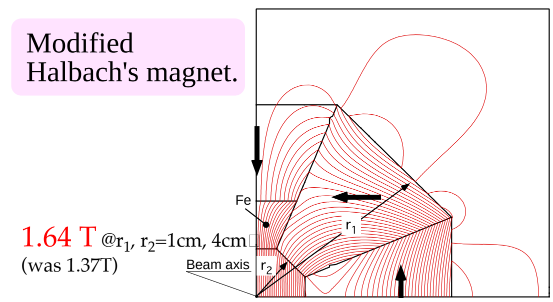

Fig. 2 Modified Halbach's configuration.

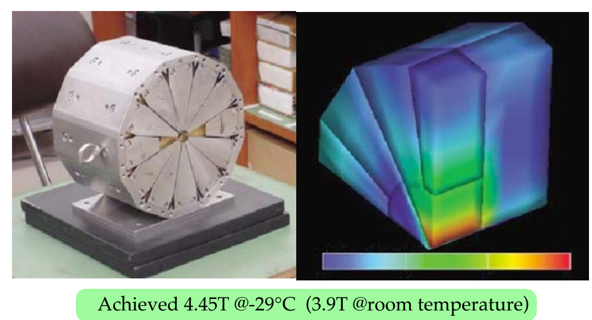

Fig. 3 4.45T permanent magnet dipole.

QUADRUPOLE

Fig. 4 shows the flux plot of the designed permanent magnet quadrupole calculated by PANDIRA. The field strength and gradient are also shown in the figure. The

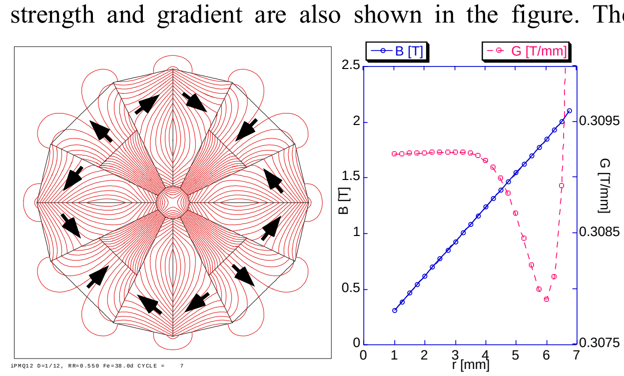

Fig. 4 Permanent Magnet Quad with saturated iron.

field gradient is calculated as 0.3T/mm. The inner diameter and outer diameter are ø14 mm and ø100 mm, respectively. It is segmented into 12 trapezoidal sections and inner parts of four of them are replaced by soft iron material. The outer diameter of the SUS case is ø130 mm, which can leave the space for outgoing beam after the interaction point when the crossing angle of the two colliding beam is set to 0.02 radian assuming that the distance between the interaction point and the edge of the quadrupole is 3.5m. The beam separation increases towards the far end of the 2m-length quadrupole lens.

The 3D calculation is performed on the geometry shown in Fig. 5. The total length is 10cm and that of the iron poles are 9cm. Both the ends of the iron poles are capped by permanent magnet pieces, which push the flux in and reduces the fringing field. Fig. 6 shows the calculated results of the field gradients along the axis. This figure also shows the cases when the iron poles are not used and when the iron poles are extended till the ends. It shows the effect of the saturated iron in the PMQ application. Although the integrated gradient is the strongest in the case of full length iron pole, it exhibits longer fringing field and slightly less peak gradient at the center (z=0) and thus we adopted the former option to demonstrate both the strong focal strength and the high gradient. Fig. 7 shows the assembled PMQ where the endplate is removed. The extra small magnets are glued on the endplates and are not shown.

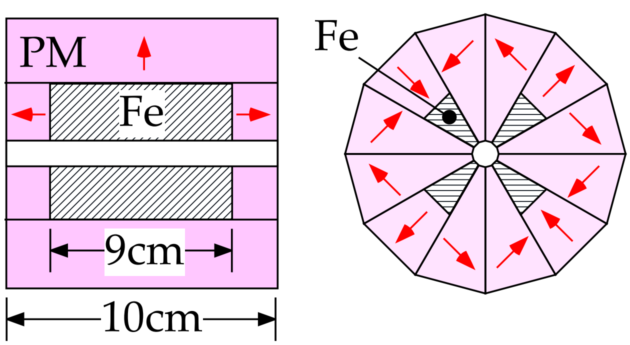

Fig. 5 3D configuration of the PMQ. The iron poles are 1cm shorter and replaced by permanent magnets pushing the flux inside to reduce the fringing field.

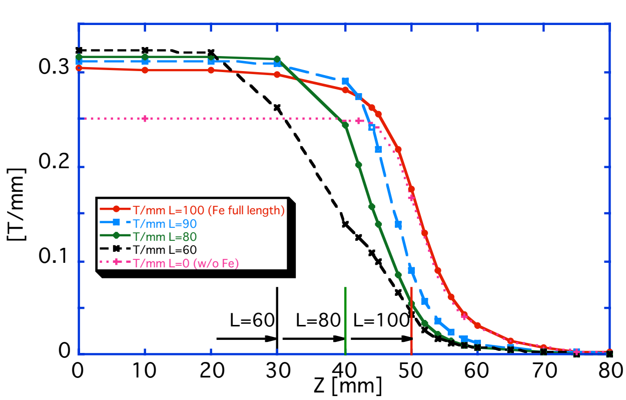

Fig. 6 Calculated field gradient along the axis.

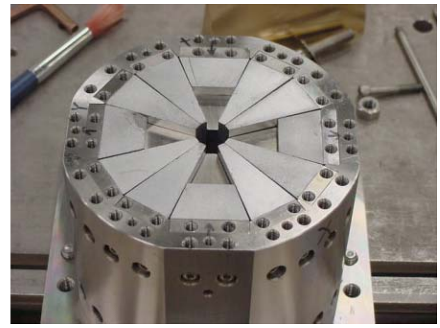

Fig. 7 The PMQ with saturated iron.

MEASURED RESULTS

The magnet was shipped to SLAC and kindly measured by them. The magnet was placed on V-blocks and the integrated field was measured by a rotating coil[8] (see Fig. 8). The measured integrated field gradient was 28.5 [T] while the calculated value was 29.7 [T] for full length. About 5% difference seems reasonable within our experience. Harmonics components are shown in Fig. 9. The dipole component comes from misalignment of the magnet center against the coil axis. Other components except n=2,6,10…, which are inhibited by the rotation symmetry, have somewhat larger amplitudes.

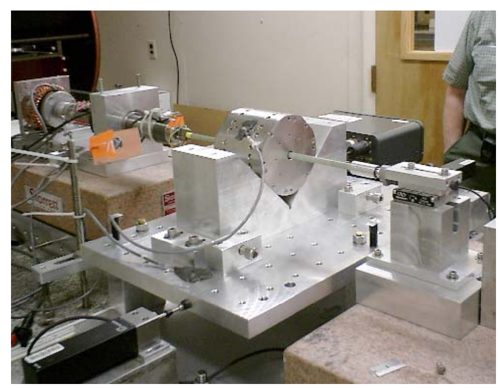

Fig. 8 Magnetic field measurement setup at SLAC.

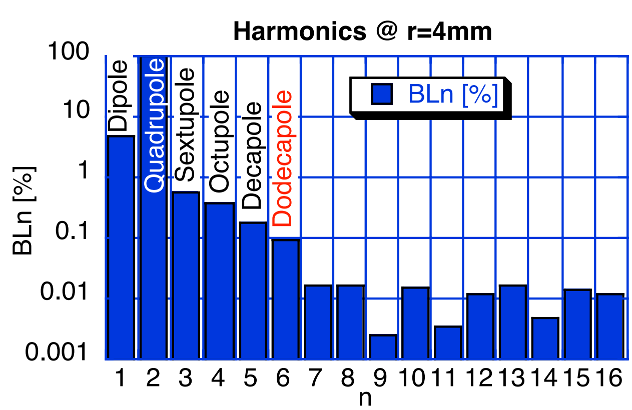

Fig. 9 Harmonics components. Except quadrupole (n=2) and dodecapole (n=6) components are larger than expected.

ADJUSTABILITY

The adjustability of the focal strength down to 25% is required for a calibration run with 1% resolution. The focal strength adjustments on the PMQs have been realized by adjusting a rotation angle of each separated PMQ in a system such as a triplet, while this scheme introduces skew components. Because the skews have to be strictly inhibited in the linear collider application, this scheme is not directly applicable. The full 90 degree rotation, however, just switches the focus Q to defocus Q and vice versa. Thus, the 2-m length quadrupole lens will be divided into ten 20-cm units and each unit will be divided into four different PMQs with binary way (see Fig. 10). When a smallest PMQ that has 0.5% focal strength of the total system flips 90 degree around its axis, the total focal strength changes 1%. One issue for such scheme is that the mechanical rotation may cause a magnetic center movement. Magnetic force between each PMQ may increase such effect, which can be reduced by putting a space with reduction of the packing factor. For shorter PMQs, the saturated iron technique may not be applicable because they are too short to keep the operating point high. This may make the total length longer.

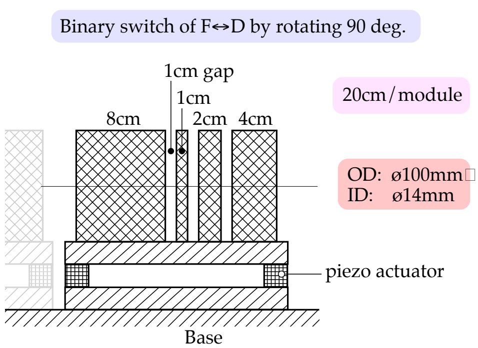

Fig. 10 Binary stepwise PMQ unit. Each PMQ can be flip 90 degree around its axis.

We are also investigating another way to adjust the focal strength (see Fig. 11). There are two PMQs; inner PMQ and outer PMQ. The outer PMQ is nothing but a normal PMQ with a large bore hole. The inner PMQ has iron poles instead of magnets. After we flip the outer ring (left to right figure), the field gradient in the bore decreases down to a few %. The inner PMQ can be fixed, while the outer PMQ rotates. One drawback is larger torque needed to rotate. This may be reduced when the

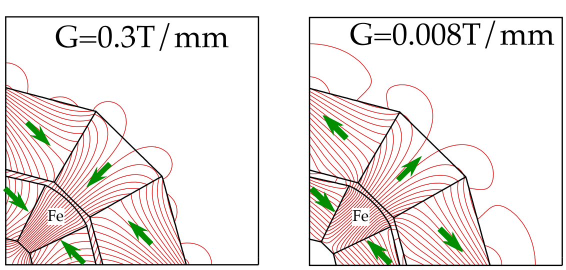

Fig. 11 Double ring scheme.

dynamic range is kept small. Thus the magnets of the inner PMQ will be fixed on the rigid iron poles that has full 20-cm length (Fig. 12). Longitudinally separated outer PMQ should have less sensitivity on the center movement when they rotate because they are far from the axis.

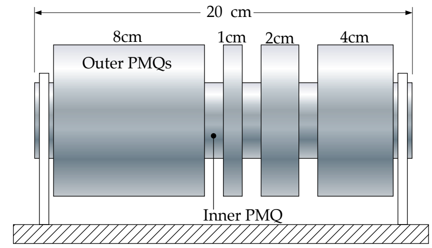

Fig. 12 Alternative way of the focal strength adjustment.

CONCLUSION

The permanent magnet quadrupole with saturated iron demonstrated the fairly high magnetic field gradient compaered with the conventional one. The measured gradient agrees with calculated one within 5% difference. The higher harmonics components are observed in spite of the rotational symmetry, which is under investigation. We are preparing a measurement apparatus such as a heater and a temperature controller for temperature dependence.

In order to avoid a skew component while adjusting the focal strength, binary switch scheme will be adopted. A mechanical system for the adjustment of the focal strength is under investigation.

ACKNOWLEDGEMENT

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REFERENCES

[1] K.Halbach, IEEE, Trans., NS26(1979),3882
[2] K.Halbach, NIM,169(1989) 1
[3] K.Halbach, NIM,187(1981) 109
[4] K.Halbach, NIM,198(1982) 213
[5] CERN Courier(International journal of high energy physics), Magnet becomes more compact volume 41,number 7,september 2001,page 9
[6] M. Kumada, T. Fujisawa, Y. Hirao, M. Endo, M. Aoki, T. Kohda, Y. Iwashita, Bolshakova, R. Holyaka, "Development of a Model 4 Tesla Dipole Magnet", pac2001, June, 18-22, 2001, Chicago
[7] M.Kumada, T.Fujisawa, Y.Hirao, M.Endo, M.Aoki, T.Kohda, Y.Iwashita, Bolshakova, R.Holyaka, "Development of high field permanent magnets", MT17 (International magnet technology conference), 9/24-28,2001,Geneve
]8] C.E. Rago, C.M. Spencer, Z. Wolf, "High Reliability Prototype Quadrupole for the Next Linear Collider", 17th InternationalMagnet Technology Conference