View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by UNT Digital Library

SLAC-PUB-13090

# MODIFICATION AND MEASUREMENT OF THE ADJUSTABLE PERMANENT MAGNET QUADRUPOLE FOR THE FINAL FOCUS IN A LINEAR COLLIDER*

Y. Iwashita, M. Ichikawa, Y. Tajima, H. Fujisawa, Kyoto Univ., Uji, Kyoto, JAPAN
S. Kuroda, T.Okugi, T.Tauchi, KEK, Tsukuba, Ibaraki, JAPAN
M. Kumada, NIRS, Chiba, JAPAN
C. M. Spencer, SLAC, Menlo Park, Ca, USA.

*Abstract*

An adjustable permanent magnet quadrupole has been developed for the final focus (FF) in a linear collider. Recent activities include a newly fabricated inner ring to demonstrate the strongest field gradient at a smaller bore diameter of 15mm and a magnetic field measurement system with a new rotating coil. The prospects of the R&D will be discussed.

## INTRODUCTION

We have been studying permanent magnet quadrupoles (PMQ)[1] for the final focus in a linear collider since 2002. The first prototype using magnetically saturated soft magnetic material was fabricated as a fixed strength magnet and showed an integrated field gradient of 28.5 T, where the length, bore and outer diameters were 10cm, ø14mm and ø13cm, respectively [2].

After the successful demonstration of the fixed strength PMQ, a variable PMQ was designed and fabricated using the “double ring structure”: the PMQ is split into two nested rings; the outer ring is sliced along the beam line into four parts and is rotated to change the strength (see Fig. 1)[3,4]. It produced over a 120T/m field gradient and achieved 24T integrated gradient with ø20 mm bore diameter, 100 mm outer magnet diameter and 20cm pole length. The integrated strength of the PMQ was adjustable in 1.4T steps. Because the inner ring is fixed and only the outer ring sections are switched between zero and 90-degree rotation angles, the magnetic center movement is less sensitive to any mechanical errors. The skew components are suppressed because of the binary rotation angles (there is no source of skew components for a perfectly symmetric case). The large temperature coefficient (~ $-10^{-3}$/°C) in remnant magnetic field ($B_r$) of the magnet material NdBFe is compensated by putting MS alloy materials, which has large temperature coefficient [3]. The latest modification on the variable strength PMQ is a reduction of the bore radius, by fabricating a new inner ring that has smaller bore radius ø15mm (see Fig.2) to make a stronger gradient.

## NEW MEASUREMENT SYSTEM

A rotating coil system to measure the field has been designed and is being assembled. A one turn rotating coil is printed on a flexible print circuit sheet and glued on a quartz rod (see Fig. 3). Although the coil can be placed only on the surface, the thermal expansion coefficient of quartz is very small and the output should be stable against environmental temperature drift. Two coils are placed at the symmetric positions to the rod center and their output signals are added and subtracted before amplification. Each amplified signal is integrated to eliminate the effects from the modulation of the angular speed of the coil. The amplified two signals are simultaneously recorded to allow measurements of small harmonic components amongst a large component, such as a sextupole component amongst a large quadrupole.. Three values of opening angle between the 2 coils can be used to optimize the output for harmonics measurements (see Fig.4). An ADC with 24-bit resolution is used to enhance the ability to measure small harmonic components from each coil.

Since the delivery of the new rotation coil measurement system was delayed, we measured the bore field by a Hall probe (Group-3 MPT-141) to get preliminary data. The

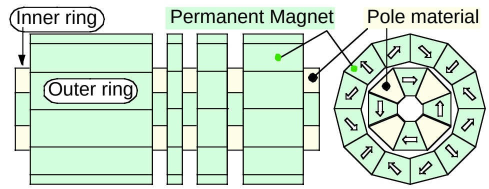


Figure 1: The double ring structure.

Figure 2: Right: the initial ø20mm bore. Left: new ø15mm bore.

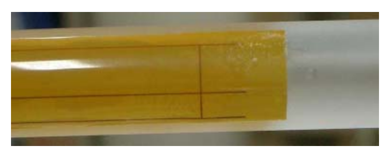

Figure 3: One turn measuring coil printed on a flexible circit sheet glued on a quartz rod.

*Work partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (A), 14204023(2002) , 18204023(2006) and the U.S. Department of Energy under contract number DE-AC02-76SF00515.

*Contributed to Particle Accelerator Conference (PAC 2007), 6/25/2007-6/29/2007, Albuquerque, NM, USA*

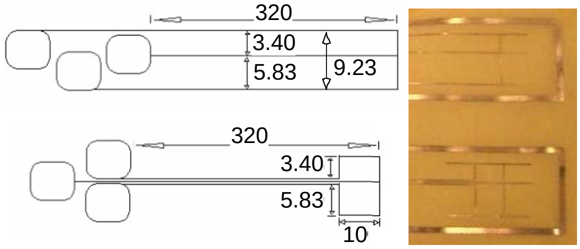


Figure 4: Tangential coils that enable three values of opening angle: $\pi/13$, $\pi/7$ and $(1/12+1/7)\pi$. Short coil (bottom) will be used to measure the longitudinal field distribution. The dimensions are in mm.

maximum field gradient increased to 190T/m. This measurement also enabled us to show the gradient varied longitudinally as the integrated strength was changed in 15 steps (see Fig. 5). As expected from TOSCA simulations, the field distributions are not uniform and the centroid of the integrated strength moves along the axis up to ±50mm as the strength changes. This excursion of the centroid is almost half of the PMQ length; it can be reduced by using two PMQ's back to back [5].

## ADAPTING NEW CROSSING ANGLE

Because the outer ring of the double-ring structure tends to overlap the location of the outgoing beam for a 14 mradian crossing angle, a new PMQ configuration of the final focus doublet with a simple ring is under investigation.

An adjustable strength PMQ, which is divided into five touching rotatable rings, was reported by R. L. Gluckstern, et al. [6]. Fig. 6 shows the configuration of such a set of five rings whose lengths are the ratios as shown in the

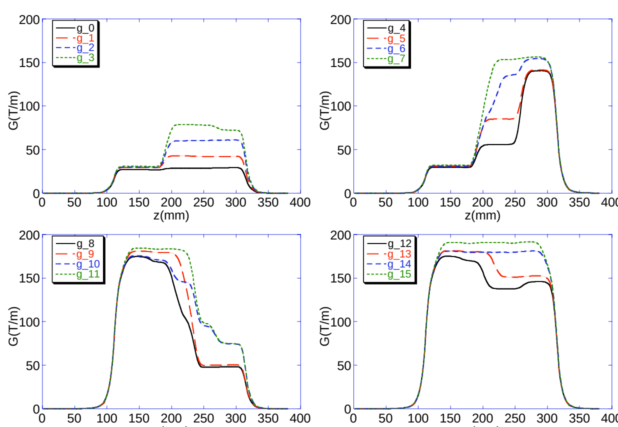


Figure 5: Longitudinal field distributions at 15 steps.

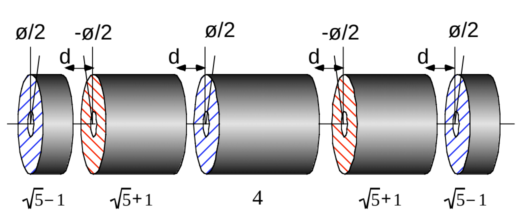


Figure 6: Five ring singlet. The numbers under the rings are the length ratios for the skewless condition when d=0.

figure. The rotation angles, ø of the PMQ rings at even positions are opposite in sign against those at odd positions. The transfer matrix for such a system should be expressed by 4x4 matrix M, while those for each PMQ are written as:

$$\mathbf{M}0=\begin{pmatrix}\mathbf{M}0_{xx} & \begin{matrix}0&0\\0&0\end{matrix}\\ \begin{matrix}0&0\\0&0\end{matrix} & \mathbf{M}0_{yy}\end{pmatrix},\ \mathbf{M}1=\begin{pmatrix}\mathbf{M}1_{xx} & \begin{matrix}0&0\\0&0\end{matrix}\\ \begin{matrix}0&0\\0&0\end{matrix} & \mathbf{M}1_{yy}\end{pmatrix},\ \mathbf{M}2=\begin{pmatrix}\mathbf{M}2_{xx} & \begin{matrix}0&0\\0&0\end{matrix}\\ \begin{matrix}0&0\\0&0\end{matrix} & \mathbf{M}2_{yy}\end{pmatrix}.$$

Then the total transfer matrix **M** is calculated as:

$$\mathbf{M}=\mathbf{R}\cdot\mathbf{M}2\cdot\mathbf{R}^{-2}\cdot\mathbf{M}1\cdot\mathbf{R}^{2}\cdot\mathbf{M}0\cdot\mathbf{R}^{-2}\cdot\mathbf{M}1\cdot\mathbf{R}^{2}\cdot\mathbf{M}2\cdot\mathbf{R}^{-1}.$$

By rewriting with sub matrices, **M** can be written as

$$\mathbf{M}=\begin{pmatrix}\mathbf{M}xx & \mathbf{M}xy\\ \mathbf{M}yx & \mathbf{M}yy\end{pmatrix},$$

and the off-diagonal sub matrices become negligible when the lengths of the rings satisfy the relations stated before. It should be noted that the distances between rings are zero (d=0) in above case. A similar problem was solved for a case with d=1cm case where summed PMQ length L0+2L1+2L2 is 20cm (total length is 24cm including four gaps), keeping L0+2L2-2L1=0. The rotation matrix **R** should be substituted by $\mathbf{R}\cdot\mathbf{D}$, where matrix **D** denotes a 1cm drift space. The off diagonal sub matrices are expanded in series up to 5th order for a solution. The ratios are solved as L2:L1:L0=1.81046: 5: 6.37909.

## SINGLET TRAIN CONFIGURATION

Assuming a field gradient of 140T/m and using 12 units of the five-ring-singlets, the total length becomes about 3m. Using this singlets train as a QD0, a preliminary fine tuning was carried out with matching requirement for Twiss parameters: $\alpha_x=\alpha_y=0$, $\beta_x$=0.021m, $\beta_y$=400$\mu$m, $\eta_x$=0 at IP, starting with the ILC deck "ilc2006b.ilcbds1" ( 14mrad version ). The final ø of PMQ is 6.58 degree. Then off momentum matching was performed by re-optimizing K2 of sextupoles looking at the beam size at IP [7]. The coupling between x and y was well suppressed and the final beam sizes at IP are $\sigma_x/\sigma_y$ = 656/5.44nm for $\gamma_{ex}/\gamma_{ey}$=9.2e-6/3.4e-8m and $\sigma\delta$=6e-4 ( 636 / 5.25nm for original design ). Although the optimization was not fully performed such that octupoles were fixed, the result seems promising (see Fig. 7). Further optimization will improve the results. A rough sketch of the closest optics components is shown in Fig. 8. These magnets QD0 and QDEX1 together with SD0 can be fabricated with permanent magnets, which are buried in the detector magnet.

## EXTERNAL FIELD OF PMQ

Assuming an $L^*$ of 4.5m, the distance between the in-coming and out-going beam is 63mm at the $L^*$. The bore size required for the outgoing beam would be ø25mm at 4.5m. The external stray field at the outgoing beam, which is located from x=50mm to 75mm (see Fig. 9), is less than 10 Gauss. An iron case as the PMQ holder will reduce the field to one hundredth (see Fig. 10). The external magnetic field from the detector solenoid has to be dealt with when soft magnetic material is used; the iron case should be made of laminated iron with less enough packing factor to have less longitudinal permeability.

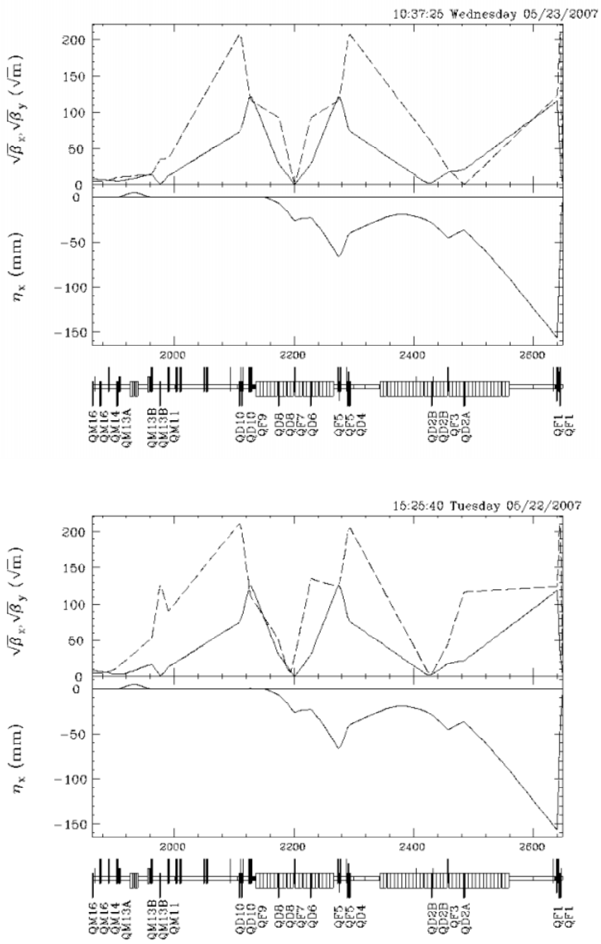

Figure 7: Optics with PMQ. top: original, bottom: using PMQ with partial optimization.

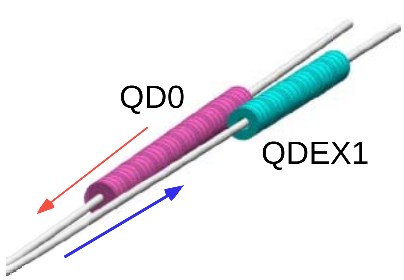


Figure 8: Rough sketch of QD0 and QDEX1.

## DISCUSSION

One of the remarkable advantages of the PMQ is its vibration free characteristics. A jitter in the FF optics system will add jitters to the beam spot position at the Interaction Position (IP). Although such a beam jitter will be suppressed by a feedback system, it is desirable to have less vibration in the optics system. The singlet train configuration allows a continuous adjustment of the strength. More study is needed to complete a mechanical design of a set of quadrupoles near IP. Fabrication of a prototype of a unit in this fiscal year will help this study. The design will be targeted for QD0 in the ATF2 beamline at KEK for a real beam test.

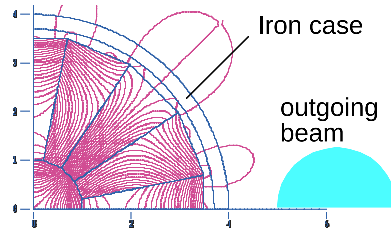


Figure 9: PMQ and out going beam.

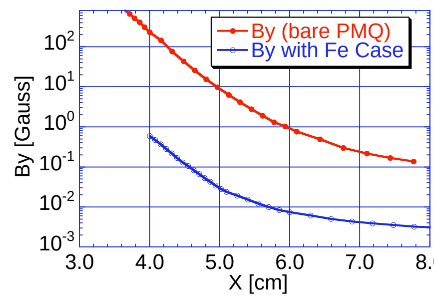


Figure 10: External stray field of PMQ.

## REFERENCES


[1] K.Halbach, IEEE, Trans., NS26 (1979), p.3882, NIM 169 (1979) NIM 187 (1981), NIM 198 (1982)

[2] Y. Iwashita, T. Mihara, E. Antokhin, M. Kumada, M. Aoki, “Permanent Magnet Quadrupole for Final Focus for Linear Collider”, PAC03, May 12-16, Portland, OR, p2198-2200: http://accelconf.web.cern.ch/accelconf/p03/PAPERS/WPAB069.pdf

[3] T. Mihara, Y. Iwashita, M. Kumada. C.M. Spencer, E. Antokhin, “Super Strong Permanent Magnet Quadrupole for a Linear Collider” IEEE Transactions on Applied Supercond., **14**-2, pp.469-472, 2004

[4] T. Mihara, Y. Iwashita, M. Kumada, C. M. Spencer, “Variable Permanent Magnet Quadrupole”, IEEE Trans. on Applied Supercond., **16**-2, pp.224-7, 2006

[5] Y.Iwashita, et al., “Permanent magnet option for final doublet and octupole as tail fold”, 9th ACFA ILC Physics and Detector Workshop & ILC GDE Meeting, Feb. 4-7, 2007,IHEP,Beijing, China

[6] R.L. Gluckstern and R.F. Holsinger: Adjustable Strength REC Quadrupoles, IEEE Trans. Nucl. Sci., Vol. NS-30, NO. 4, August 1983, http://epaper.kek.jp/p83/PDF/PAC1983_3326.PDF

[7] Y.Iwashita et al. :Permanent magnet final quadrupole, LCWS2007/ILC2007, 29May4June DESY Hamburg, http://ilcagenda.linearcollider.org/getFile.py/access?contribId=130&sessionId=97&resId=0&materialId=slides&confId=1296