PREPARATION OF ADJUSTABLE PERMANENT MAGNET QUADRUPOLE LENS FOR BEAM TEST AT ATF2

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Abstract

A permanent magnet quadrupole lens with continuously adjustable strength originally designed by Gluckstern was fabricated. It consists of five PMQ rings that rotate on their axis, where odd and even numbered rings rotate oppositely but with the same absolute angle. By setting their lengths appropriately, the coupling between x and y components can be minimized. In order to reduce multipole components higher than quadrupole, we adjust positions of magnet wedge pairs. The magnetic center and the mechanical center of the PMQ rings have to be adjusted by measuring harmonics of fields in magnets. In order to carry out the beam test, a high precision movable table for the lens system is also fabricated. This table can evacuate the lens system from the beam line completely without vacuum breaking, which should ease the evaluation of the system at decreased strength region.

INTRODUCTION

Permanent magnet devices can be strong, stationary and compact focusing elements. A focusing magnet is required to have continuously adjustable field strength for handling a practical beam. A five-ring-singlet design was proposed by Gluckstern. X-Y coupling effect caused by a skew of each ring can be theoretically cancelled in this design. The effect of x-y coupling may be fatal to a beam whose scale in x-plane and y-plane are different as in a case at interaction point of ILC. Then we also should minimize multipole field components higher than the quadrupole field component of the each five PMQ ring not to couple the beam emittance between x and y.

In order to test in a real beam line, ATF2, we fabricated the prototype 5-ring singlet variable PMQ which has an inner bore radius of 25mm with Neomax 48 H magnet. This PMQ can provide a field gradient of 30 T/m in the bore.

MAGNETIC FIELD TUNING

We tune the multipole field components a_n and b_n with changing the wedge positions, where n denotes the n-th harmonics, while a_n and b_n are the real and imaginary components, respectively. For example, Fig. 1 and 2 show the case that the first-wedge is displaced by 1mm. The coefficient da_n/dr_m ($=C_{2n-1,m}$) and db_n/dr_m ($=C_{2n,m}$) can be estimated by taking the differences before and after the displacement of the m th-wedge by the simulation code PANDIRA[5] . From the measured harmonics components, the distance r_m- to reduce the multipole field

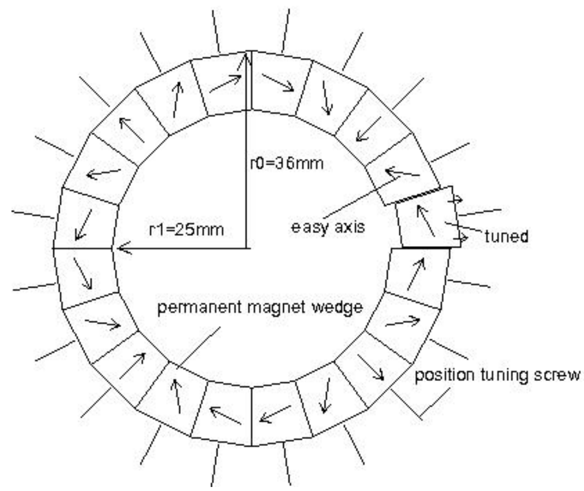

Figure 1: Design of Halbach model PMQ with 20 wedges of permanent magnet is shown. The first wedge is displaced by 1mm in this figure.

components can be estimated by the least squares method with weight. We use less weight for higher harmonics since they have less importance.

It should be noted that the third line of coefficient matrix C has the similar values for all elements since the contribution to the quadrupole field from each wedge is almost the same. On the other hand, the forth line is all zero, since no wedge can generate a skew component. Because each wedge is pushed by screws from the holder shell and tightly positioned squeezing each other in the holder, each wedge cannot be moved independently. Thus the forth has to be omitted. We describe this mechanical constraint condition,

$$\sum_{m=1}^{20} \Delta r_m = 0 \tag{1}$$

which is implemented by the third line: the line is replaced by all 1's. PANDIRA is able to calculate multipole components up to 14th-order easily, then we use all coefficient (n_{max}=14). The correction value Δr_m can be derived by Eq. 3.

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$$\mathbf{C}=\begin{pmatrix} C_{1,1} & \dots & \dots & C_{1,20} \\ C_{2,1} & \dots & \dots & C_{2,20} \\ 1 & \dots & \dots & 1 \\ C_{5,1} & \dots & \dots & C_{5,20} \\ \dots & \dots & \dots & \dots \\ C_{28,1} & \dots & \dots & C_{28,20} \end{pmatrix}$$

$$\Delta r=\left(\Delta r_1 \quad \dots \quad \dots \quad \Delta r_{20}\right)^{\mathrm{T}}$$

$$\mathbf{b}=\left(a_1 \quad b_1 \quad 0 \quad b_3 \quad \dots \quad b_{28}\right)^{\mathrm{T}} \tag{2}$$

$$\mathbf{w}=\left(2^0 \quad 2^0 \quad 2^{-1} \quad 2^{-2} \quad 2^{-2} \quad \dots \quad 2^{-13} \quad 2^{-13}\right)^{\mathrm{T}}$$

$$\mathbf{W}=\mathrm{diag}\ (w)$$

$$\Delta\mathbf{r}=(\mathbf{C}^{\mathrm{T}}\mathbf{W}\mathbf{C})^{-1}\mathbf{C}^{\mathrm{T}}\mathbf{W}\mathbf{b} \tag{3}$$

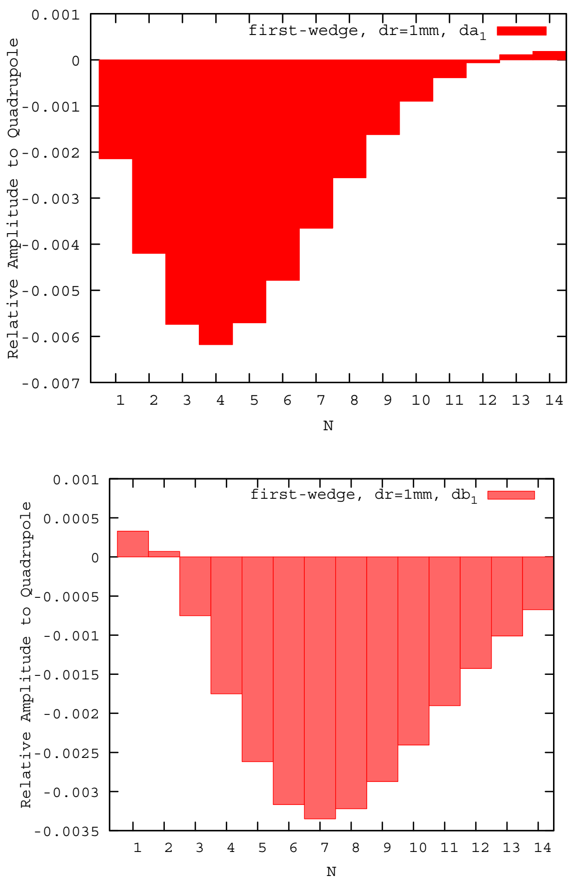

Figure 2: The variations of relative amplitude to quadrupole when the 1st wedge is displaced by 1mm are show. Real part (top) and imaginary part (bottom).

ADJUSTMENT

In order to reduce multipole components sufficiently, high reproducibility is necessary for measuring harmonics of magnetic fields. Since the resolution of the position tuning screws is about 10-20 µm, it is desirable that mechanical position reproducibility is at least less than 5µm. Our instrument for measuring harmonics is shown in Fig 3. From upside, a coil for measurement, a PMQ ring, a ring holder, a pillow block, an encoder and a pulse motor are seen. During measurement, the coil is fixed on stage and the PMQ ring is mechanically held in rotation axis. The mechanical position reproducibility is is less than 5µm. We repeat measurement of harmonics and tuning with the algorithm for about a ten times. The reduction of multipole components is shown in Fig. 4. We reduce all components to one or two orders small.

A method to achieve further improvement is under study such as to use more precise coefficient matrix.

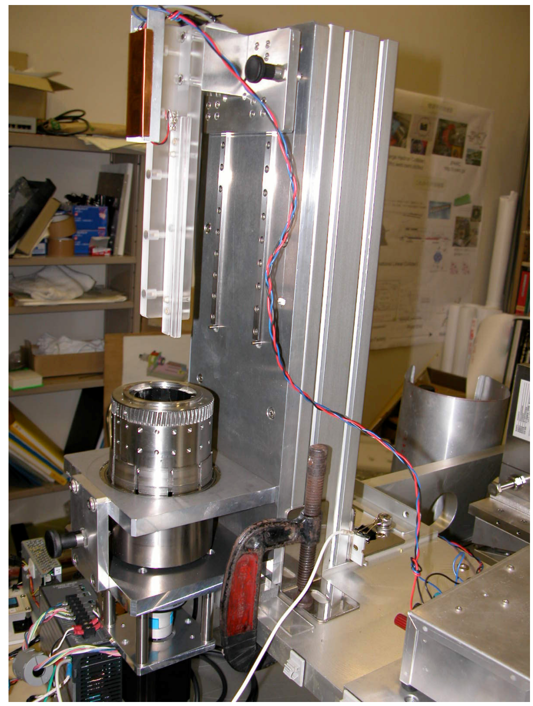

Figure 3: The instrument for measuring harmonics.

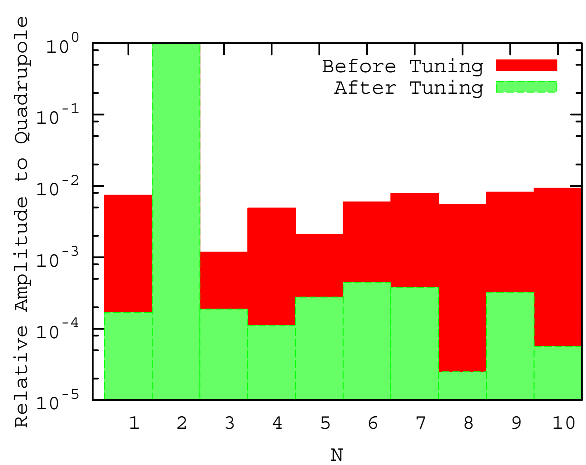

Figure 4: The absolute amplitude of measured multipole components of harmonics, $|a_n+ib_n|$ is shown. Before tuning (red) and after tuning (green).

BEAM TEST AT ATF2

The PMQ system is planned to be installed in the ATF2 beam line in this autumn. When we introduce new optics device like this we have to gather practical experience of handling, installation and alignment technique also to evaluate the feasibility of the system. For that purpose, the first beam test is planned at the ATF2 beam line. Although the PMQ is designed as one of the final focus system, initial test will be carried out at the upstream position to avoid any conflictions with the other activities around the final focus area (see Fig.5). The wire position monitors can be used to measure the beam movements caused by the system during the strength change by rotating the rings. X-Y coupling is of concern also.

The magnet system will be precisely aligned and adjusted by a mover (see Figs. 6,7). The prepared magnet mover can also evacuate the magnet system from the beam line without vacuum break, which enable us to evaluate the real magnet center by asking the beam about its deflection. The feature should also minimize any interference in a series of the machine time schedules.

CONCLUSION

This tuning method allows us to shape the magnetic field components of the PMQ ring. Now we are tuning other four PMQ rings and improving coefficient matrix to be more precise in order to reduce dipole and sextupole components more quickly. After tuning we are planning to assemble five-ring-singlet PMQ and a beam test at ATF2.

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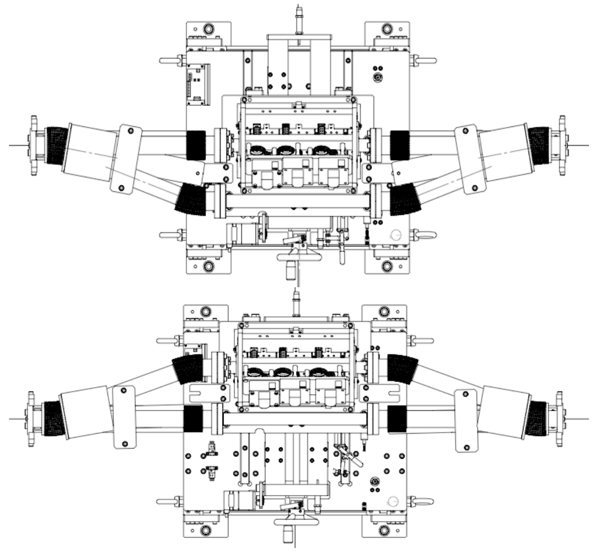

Figure 6: The magnet system can be evacuated instantly without vacuum break. Top figure shows in-line position, and bottom one shows off-line position.

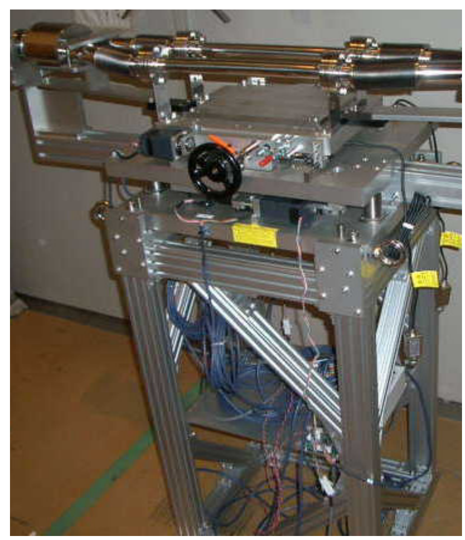

Figure 7: Fabricated magnet mover.

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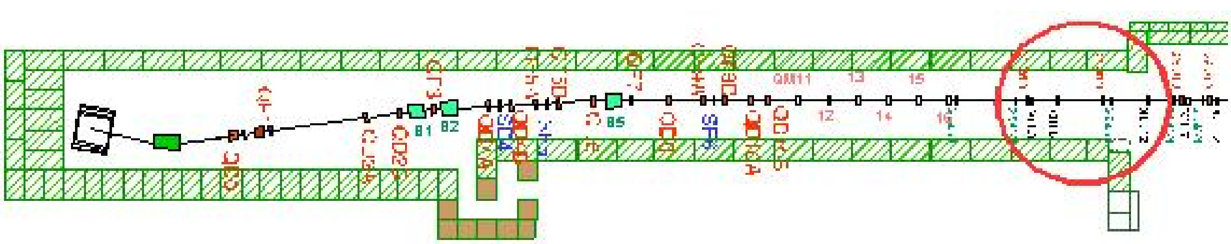

Figure 5: ATF2 beamline. The initial beam test for the PMQ system will be performed at the upstream position.