COMPLEX DIPOLE QUADRUPOLE MAGNET

M. J. Shirakata, H. Sato, KEK, Tsukuba, Japan

Abstract

In case of adding a new component into the accelerators, a problem on spacing often occurs. Generally, some kinds of correction magnets are necessary for the stable beam operation and people want to put the additional equipments in it when the machine upgrade is tried. But it is not always sure that the enough space was left. In such a case, it should be taken into the consideration that replacing the single function elements by the complex ones. At the KEK-PS, the complex dipole quadrupole magnet was developped for this purpose.

1 INTRODUCTION

Since 1995 at the KEK-PS, many studies and efforts have been done in order to improve the main ring beam intensity for the neutrino experiments. When a physical aperture was surveyed, a large amount of modulation on the steering kick angles was found. The KEK-PS main ring steering system consists of 56 dipole magnets. One is special, two are large but the others are completely same type of magnets. Because the kick angle is defined by a multiple of the magnetic field and lattice betatron function, it is natural to consider that the modulation on steering kick angles comes from the betatron function modulation. The trim quadrupole system was proposed in order to compensate the betatron function modulation.

The KEK-PS main ring was constructed more than 20 years ago. Because it already has many kinds of equipments in its straight sections, not enough space was left for the trim quadrupole system. For the harmonic correction of the betatron function, it is better to insert the trim quadrupoles periodically with the same distances from the main quadrupoles. Replacement of the present steering magnets with the complex functioned ones was the unique solution.

2 DESIGN WORK

2.1 Boundary Conditions

The steering magnets are placed with the beam position monitors involving the vacuum flange connection in it. The very large magnet aperture was needed compared to the magnet length. It must work as a steering magnet without downgrading the present system[1] with the present power supplies. Table1 shows the required specifications. The letters 'L','R','U' and 'D' of a quadrupole coil mean the left, right, up and down, respectively. The dipole quadruple complex functioned magnet was proposed.

Table 1: Specifications of the complex dipole quadrupole magnet

Bore radius	110 [mm]
Core length	200 [mm]
Quadrupole coil(L,R)	210 [truns/pole]
Quadrupole coil(U,D)	220 [truns/pole]
Dipole coil	1320 [truns/pole]
Maximum current(Q)	10 [A]
Maximum current(D)	6.5 [A]
Maximum field gradient	>7 [G/cm]
Maximum dipole field	>250 [G]
Operation mode	Bipolar patterned

2.2 Magnetic Field Design

The complex dipole quadrupole magnet was designed based on the Panofsky magnet[2][3] in order to excite the clean quadrupole field with the dipole one, by mainly using the ELF-MAGIC program which can simulate the 3D magnetic field. The word 'clean' means that there are very little parasitic higher multipoles. Fig.1 and Fig.2 show the expected quadrupole field. Though the fringe field is not so small due to the large magnet aperture, it is not a big problem because the quadruple field can be cleanly excited.

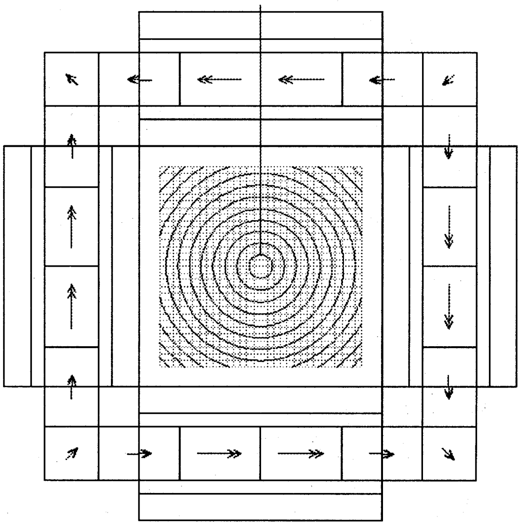

Figure 1: Front view of the quadrupole field

The multipole coefficients estimated by ELF-MAGIC are listed in Table2 according to the magnetic field excitation. The multipole coefficients are defined as:

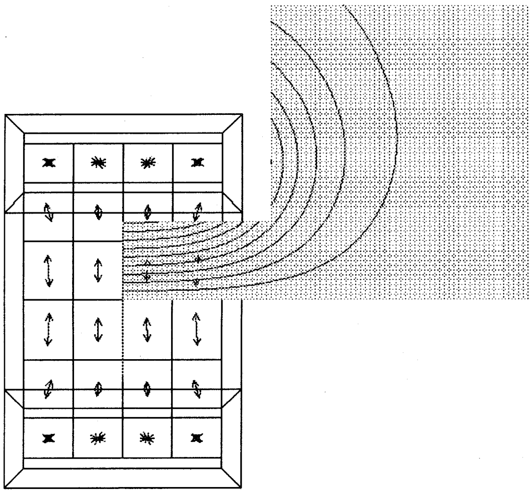

Figure 2: Side view of the quadrupole field

$$Bz = a_0 + a_1 x + \frac{a_2 x^2}{2} + \frac{a_3 x^3}{6} \qquad (1)$$

Table 2: Estimated multipole coefficients with dipole and quadrupole excitation

	Dipole	Quadrupole
a_0 [G]	-3.14e+02	1.50e-08
a_1 [G/cm]	8.51e-03	7.31e+00
a_2 [G/cm^2]	-4.21e-01	-7.37e-10
a_3 [G/cm^3]	-1.05e-03	-1.70e-02

The quantamination from the mutipole coefficients are 400 times less than the main fields at the maximum, it is expected that they cannot be a problem.

3 FIELD MEASUREMENTS

3.1 Power Supply

- Dipole: The power supply is the same as one used for the actual steering system. (75V, 6.5A)
- Quadrupole: Metronix MSV10A-20 (10V, 20A).

They were used as DC 4.0 A current supplies.

3.2 Rotating Coil

The rotating coil has a long pipe shape and consists of one long coil three short coils. The 'long coil' is 1.5 m long. The 'short coils' are 20 mm long and located at the center and at ± 400 mm away from the center. In this measurement, long coil and central short coil are used.

3.3 Setup

The measurement setup in the PS north experimental room is shown in Fig.3. The rotating coil is supported by two pillars and the magnet was put on the floor lift. The output coil signals are connected into the spectrum analyzer: ADVANTEST R9211A. The spectrum data were stored in floppy disks and uploaded on the web(http://www-accps.kek.jp/Neutrino/Resonance/STTQ/rawdata/) for the offline analysis.

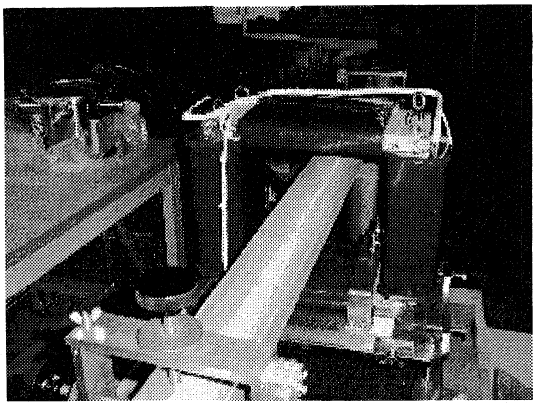

Figure 3: Measurement setup

4 RESULTS

4.1 Effective Length

The effective lengthes are obtained from the differences between the long coil and the short coil measurements. Table3 shows the dipole and quadrupole components of two types of measurements. The short coil measurements present the 20 mm long $B_0 l$ values with a central constant field B_0. Dividing the long coil measurement results by B_0, the effective lengthes were calculated as:

- 164 mm for dipole
- 206 mm for quadrupole

Table 3: Harmonic componets in [dBV]. The letters in parenthsis indicates the coil type. L stands for the long coil, S does for the short coil. Errors are statistics.

Measurement	Single excitation	Double excitation
Dipole (L)	-27.894 ± 0.003	-27.911 ± 0.003
Dipole (S)	-21.086 ± 0.003	-21.076 ± 0.002
Quad (L)	-55.462 ± 0.011	-55.754 ± 0.012
Quad (S)	-46.682 ± 0.009	-46.922 ± 0.011

This short effective length of dipole field comes from the geometrical shape of the side yokes. Due to the dipole coils, the length of side yokes are 50 mm shorter than that of the top and bottom yokes.

4.2 Dipole and Quadrupole Field Components

The dipole and quadrupole fields at the yoke center are:

- 283 G with DC 6 A
- 7.78 G/cm with DC 10 A

This result means that the required specification was satisfied though it is 10% less for dipole and it is 6% more for quadrupole than the design values.

4.3 Higher Multipole Components

The higher multipole components are listed in Table4. According to the results of ELF-MAGIC calculation, the higher components are estimated less than 0.25% at the maximum. Though the higher multipole components are slightly larger for the quadrupole excitation, they are acceptable small. The higher multipoles mainly come from the frame distortion of the magnet york.

Table 4: Higher multipole components. Values in parenthesis are the results of ELF-MAGIC.

Excitation	Sextupole	Octupole
Dipole	0.2% (0.13%)	<0.1% (<0.01%)
Quad	0.8% (<0.01%)	1.4% (0.23%)

5 REFERENCES

[1] Y.Shoji et al., Proc. of 8-th Symposium on Acc. Sci. and Tech., Nov.(1991)332-334

[2] L. N. Hand and W. K. H. Panofsky, "Magnetic Quadrupole with Rectangular Aperture", The Rev. of Sci. Inst. Vol.30 Num.10, Oct.(1959)927-930

[3] J. Budnick et al., "Design, fabrication and experimental results of a multi-purpose Panofsky magnet", NIM A368(1996)572-578