SPECIAL QUADRUPOLE MAGNETS FOR KEKB INTERACTION REGION

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Abstract

Because of the limited beam separation, normal-conducting quadrupole magnets with special shape were required for KEK B-factory (KEKB) interaction region. We have developed, tested and installed the six special shape magnets, five of these are full quadrupole magnets with field free space for the other beam. And the rest one is a half quadrupole magnet. These magnets have to meet the severe specifications such as high current density and good field distributions over a large aperture. We describe here the design and the preliminary field measurement results.

1 INTRODUCTION

KEKB is a high-luminosity electron-positron collider to study B-quark physics. KEKB has two rings, one is a 8 GeV electron ring (HER) and the other is 3.5 GeV positron ring (LER). HER and LER cross at the interaction point (IP) with ±11 mrad crossing angle. The general outline and overall parameters of the KEKB accelerator are given in [1].

Special quadrupole magnets are placed in the region where beam separation is small. We have four magnets (QC1LE, QC1RE, QC2LE, QC2RE) for HER and two magnets (QC2LP, QC2RP) for LER. The final vertical focusing field is supplied by a pair of superconducting magnets (QCS), which is common to the both beams and is tuned to the positron energy. A pair of QC1LE and QC1RE provides an extra vertical focusing field. The first horizontal focusing is provided by QC2LE, QC2RE for HER and QC2LP, QC2RP for LER.

These magnets have to meet specifications described below. (1) Because of the limited beam separation, the conductor thickness must be minimized. Consequently, some of these have a high current density such as 80 A/mm^2. (2) These magnets must apply the focusing or defocusing fields on electrons and positrons, independent each other. So, for beam of the other ring, a field free space must be embedded inside the magnets. (3) Since horizontal beta functions are large at QC2 magnets, a larger horizontal space than bore radius with a good field quality is required, although the beam separation is small and pole shape is truncated. The requirement of the field gradient non-linearity: Δ(B'l)/B'l $\leq \pm 1\times10^{-3}$ in the maximum amplitudes of the injected beam for each magnet.

2 MAGNET DESIGN

Parameters of these magnets are presented in the Table 1.

Five of these magnets (QC1LE, QC2LE, QC2RE, QC2LP and QC2RP) were designed as asymmetrical full quadrupole magnets whose conductor shape resembles that of septum magnet. The cross section of QC1LE magnet is shown in Figure 1. The other four "septum quadrupole" magnets have similar shape. The conductor between two beams works as a septum conductor. One beam goes through the quadrupole field center and the other beam passes the magnetic alloy shielded region. Magnetic shield is also used to mechanically fix the septum conductor against its thermal expansion and magnetic forces. To reduce the unwanted multipole components (mainly dipole and sextupole), backleg coils and trim coils are attached.

Table 1: Parameters of KEKB special quadrupole magnets. x_{max} and y_{max} is the maximum amplitudes of the injected beam in the horizontal and vertical planes.

item	unit	QC1LE	QC1RE	QC2LE	QC2RE	QC2LP	QC2RP
Field gradient	T/m	15.60	11.69	3.11	9.99	6.11	2.88
Bore radius	mm	38	70	60	60	45	42
Pole length	mm	600	600	2000	600	600	1000
Current density	A/mm^2	85	12	8	30	17	21
Coil turn	/pole	3	36	18	10	9	3
Max. currents	A	3000	800	300	1600	800	800
Power	kW	125	23	11	75	12	8
Flow rates	l/min	40.0	8.3	7.5	26.7	8.4	7.8
Water lines		12	4	4	4	4	4
Magnet size	mm^W	600	500	800	900	580	600
	mm^H	830	800	500	700	410	320
	mm^L	1100	750	2200	750	720	1080
x_{max}	mm	22	29	68	69	57	69
y_{max}	mm	21	27	13	16	10	12

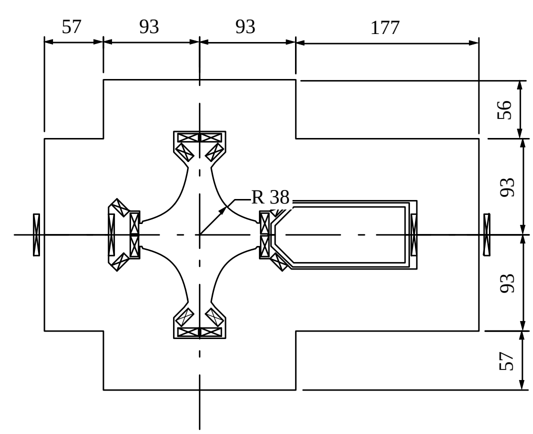

Figure 1: Cross section of septum quadrupole magnet (QC1LE)

Another (QC1RE) was designed as a half quadrupole magnet. This magnet has a half shape of full quadrupole magnet. The iron septum is expected to work as an ideal mirror plate for magnetic field. The thinnest part of the iron septum is only 3 mm thick. The design orbit goes through QC1RE at about 45 mm horizontal off-axis. The other beam passes the field free region outside the mirror plate.

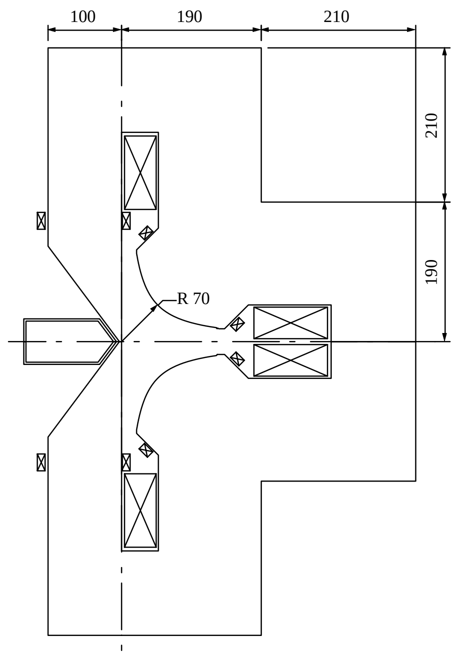

Figure 2: Cross section of half quadrupole magnet (QC1RE)

Because of asymmetric shape, these magnets have higher order multipole components which are prominent sources to degrade the dynamic aperture. The field distribution in those magnets have been calculated by using the computer code OPERA-2d[2]. We have tuned the shape of the pole face shim and the excitation current of backleg coils to meet the specifications in the design.

3 MEASUREMENTS

3.1 Excitation test of QC1LE magnet

Due to the small beam separation, QC1LE magnet has especially high current density such as about 80 A/mm^2 and high total power of 125 kW. It has 12 coil turns and each turn was cooled by separate water circuit.

The excitation test was succeeded upto enough currents of 2800 A (Figure 3). The average temperature rise of magnet water was 36 °C at the currents of 2800 A when the flow rate of water was 40 l/min.

However, the QC1LE hollow conductor size is 6 mm $\times$ 8 mm - ϕ4 mm and the flow speed of water in the conductor is higher than 4 m/sec. The lifetime of the hollow conductor may be the next problem.

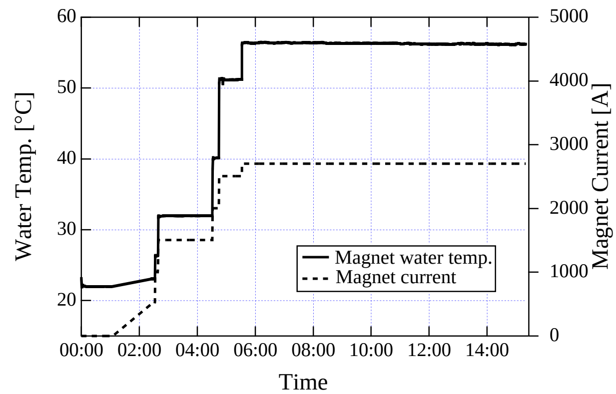

Figure 3: Magnet water temperature (solid line) and the magnet current (dashed line). The water flow rate was 40 l/min.

3.2 Fields measurements

We have measured these magnets using a harmonic coil system consisting of one radial long coil and short coil. There are three sets of such systems, one (r=55 mm, l=2600 mm) for measuring QC2LE magnet and the others (r=35 mm, l=600 mm), (r=10 mm, l=1600 mm) for measuring the other magnets. The analog signals from the coils are digitized by Dynamic Signal Analyzer (HP3562A) or Metrolab high precision integrator (PDI5025).

The final corrections were done by adding end-shim to satisfy the requirement of the field distribution. The field gradient distribution of QC1LE magnet after the corrections is shown in Figure 4. The field distribution of QC1LE is good enough for the requirement.

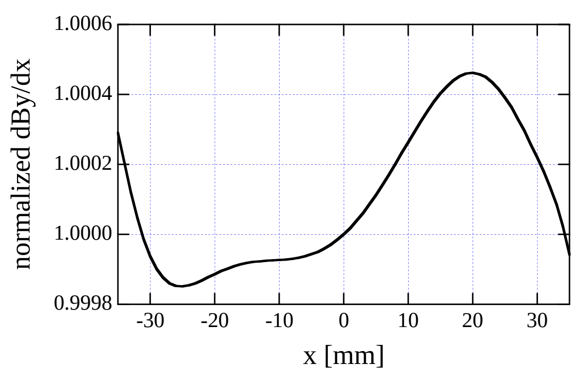

Figure 4: QC1LE measurement result of integrated field gradient uniformity at B'=13 T/m

3.3 Fields measurements of QC2 magnets

The required horizontal aperture for QC2 magnets is larger than bore radius, e.g. x_{max}=57 mm for QC2LP, of which bore radius is 45 mm. We tried to measure the field distribution by shifting small radius harmonic coil along horizontal plane. Figure 5 shows preliminary result of the field distribution of QC2LP magnet with end-shim corrections.

More corrections are necessary to satisfy the requirement. This is true for the other QC2 magnets.

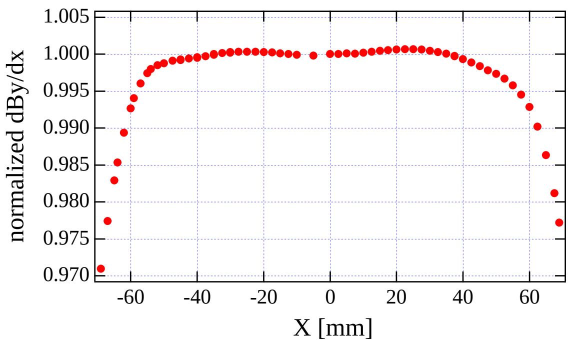

Figure 5: Preliminary measurement result of integrated field gradient uniformity of QC2LP magnet at B'=6.1 T/m

3.4 *Half quadrupole magnet (QC1RE)*

The field distribution of QC1RE magnet with end-shim corrections is shown in Figure 6. The badness of field distribution near $x = 0$ is due to a small gap of the iron septum between the upper and lower part. The magnetization of the iron septum strongly affects the field quality near $x = 0$.

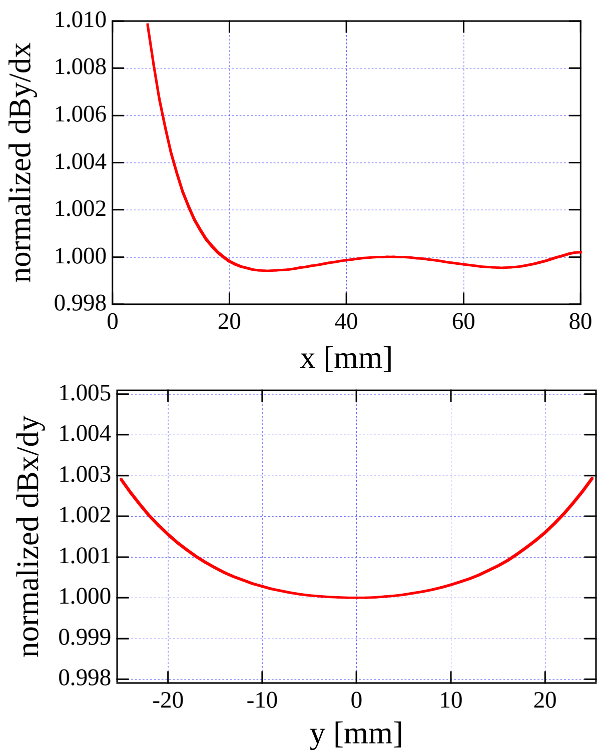

Figure 6: Measurement result of integrated field gradient uniformity of QC1RE. The coil center was $x = 46$ mm, $y = 0$ mm at B'=12 T/m.

The ratio of dipole vs. quadrupole field strength, which should be 1 in an ideal case, is 1.06 at $x = 46$ mm. This is because length of the iron septum is not enough and the iron septum does not work as an ideal mirror plate at the fringes of the magnet. The vertical field distribution is also not so good.

4 COIL OVERHEATED TROUBLE

On Dec., 1999, one coil of QC1LE magnet was overheated and burned out. The overheated coil, which is connected bus bar, is 1.5 times longer than the other coils.@After all, this trouble was caused by accumulation of CuO inside outlet horse of cooling water, which is warmest parts of the magnet.

The CuO was accumulated during only one year. So, We will add the continuous N_2-purging unit and degassing unit, which uses gas transfer membrane to the cooling water system.

5 SUMMARY

Special quadrupole magnets for the KEKB interaction region were developed and installed. Some of these magnets didn't satisfy the severe requirement.

However, the fields quality of these magnets were satisfactory at the first stage of KEKB operation.

The commissioning of KEKB started on Dec. 1st, 1998 with β_x^*=1 m, β_y^*=2 cm lattice and now these value reduce to β_x^*=70 cm, β_y^*=6 mm in both rings. No degradation in the injection efficiency, maximum current or lifetime was observed. We have successfully stored over 700 mA for LER and 500 mA for HER. We have achieved the peak luminosity of 1.92×10^{33}cm^{-2}s^{-1}[4].

To obtain higher luminosity, we will continue to improve the performance of these magnets.

REFERENCES

[1] KEKB B-Factory Design Report, KEK Report 95-7, (1995).

[2] OPERA-2d, Vector Fields Limited, Oxford, England.

[3] M. Tawada, KEKB MEMO No. 160, 2000.

[4] Y. Funakoshi et al., "KEKB Performance", in these proceedings.