PROGRESS OF DESIGN STUDY OF INTERACTION REGION QUADRUPOLES FOR THE SUPER-KEKB

M. Tawada, N. Ohuchi, Y. Funakoshi, M. Iwasaki, H. Koiso, A. Morita, Y. Ohnishi, K. Oide, K. Tsuchiya, Z. G. Zong, KEK, Ibaraki-ken, Japan

Abstract

For KEKB upgrade, we are studying the design of the final focus quadrupoles to achieve very small β-functions at the interaction point (IP). For each beam, the final beam focusing system consists of quadrupole-doublet of the superconducting and permanent magnets. In this paper, the design progress of final focusing magnets is reported.

INTRODUCTION

Upgrade of KEKB (Super-KEKB) which is based on a nano-beam scheme has been proposed. The target luminosity is 8×10^{35} cm^{-2}s^{-1} and the target total integrated luminosity is 50 ab^{-1} by 2020. The 7 GeV electrons in the high-energy ring (HER) and the 4 GeV positrons in the low-energy ring (LER) collide at one IP with a finite crossing angle of 83 mrad. The large crossing angle helps to separate the two beams quickly and to position the final quadrupole magnets closer to IP, which makes it possible to achieve small β-functions at IP. Some pertinent parameters ot IR design are listed in Table 1.

Table 1: Accelerator parameters related to IR design (May 14, 2010).

	LER	HER
Energy (GeV)	4.0	7.0
β_x^* / β_y^* (mm)	32 / 0.27	25 / 0.3
ϵ_x / ϵ_y (nm / pm)	3.2 / 8.6	5.1 / 12.8
Coupling (%)	0.27	0.25
Horz. beam size at IP (μm)	10.0	11.3
Vert. beam size at IP (nm)	48	62
Beam-beam parameter	0.09	0.09
Bunch length (mm)	6	5
Beam current (A)	3.6	2.6
Betatron tune (ν_x/ν_y)	45.53 / 45.57	45.53 / 46.57
Synchrotron tune	-0.0251	-0.0247
No. of bunches	2500	
Crossing angle (mrad)	83	
Luminosity (cm^{-2} s^{-1})	8×10^{35}	

IR DESIGN

A schematic layout of beam line near IP is shown in Fig. 1. The final vertical focusing fields for HER (LER) are provided by QC1LE and QC1RE (QC1LP and QC1RP) and the final horizontal focusing fields for HER (LER) are provided by QC2LE and QC2RE (QC2LP and QC2RP). Five superconducting quadrupole magnets (QC1LP, QC1LE, QC1RP, QC1RE and QC2RP) and three permanent quadrupole magnets (QC2LE, QC2RE and QC2LP) are designed. These superconducting quadrupole magnets are overlapped with the compensation solenoids (CS-L and CS-R) which are used for compensating the solenoid field by the Belle detector. The Belle detector which has an 1.5 T solenoid fields surrounds these magnets. QC1RP, QC1RE, QC2RP and CS-R are assembled in one cryostat and QC1LP, QC1LE and CS-L are also assembled in other cryostat. The parameters for these magnets are summarized in Table 2.

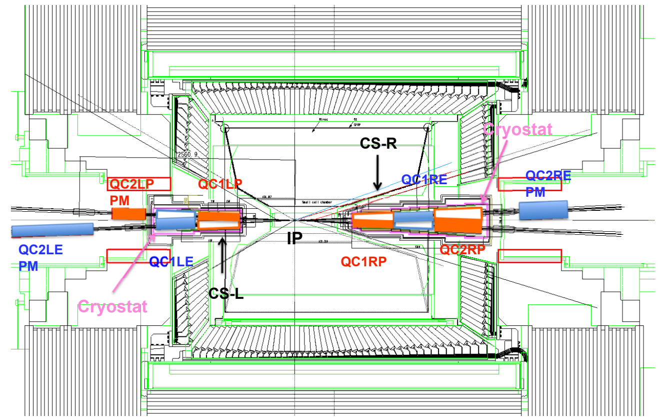

Figure 1: Schematic layout of the magnets and beam line near the interaction point, viewed from above.

MAGNET DESIGN

QC1LP and QC1RP Magnet

QC1LP and QC1RP provide the final vertical focusing for LER and these magnets are located closest to IP. The cross section of the QC1RP is shown in Fig. 2. QC1LP has the same cross section. The design parameters of these main quadrupoles are listed in Table 3. The inner radii of the quadrupole main coils are 22 mm and the effective length of QC1LP and QC1RP are 0.370 and 0.297 m, respectively. A small size cable which is 2.5 mm in height and 0.93 mm in width is required for these magnets.

In the magnet bore, four types of the correction coils are designed. The skew and normal dipole coil (a_1 and b_1) have functions to correct the QC1LP/RP magnetic center

Table 2: Locations of the magnet center from IP, effective length, field gradients, magnet type and inner diameters of vacuum chamber. S.C. means a superconducting magnet.

Magnet	Z (m)	Leff (m)	Field gradient (T/m)	Focus	Type	I.D. of Vac. ch. (mm)
QC2LE	-2.90	0.6	23.6	Horz. e^-	Permanent	70
QC2LP	-1.98	0.35	31.3	Horz. e^+	Permanent	60
QC1LE	-1.46	0.36	72.3	Vert. e^-	S.C.	30
QC1LP	-0.92	0.39	58.7	Vert. e^+	S.C.	20
QC1RP	0.91	0.28	80.1	Vert. e^+	S.C.	20
QC1RE	1.38	0.36	72.8	Vert. e^-	S.C.	30
QC2RP	1.94	0.35	31.2	Horz. e^+	S.C.	60
QC2RE	2.93	0.4	32.3	Horz. e^-	Permanent	70

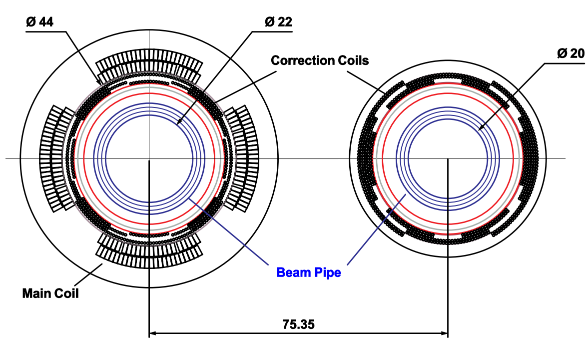

Figure 2: Cross section of QC1RP (left) and the cancel corrector coils (right) of QC1RP leakage field at the magnet center.

with ± 0.6 mm and the skew quadrupole (a_2) can rotate the mid-plane of the quadrupole field with ± 15 mrad. The octupole (b_4) of 6400 T/m^3 is used to improve dynamic apertures.

In the cryostat, the beam pipe is located and should be kept at room temperature in the vacuum condition of the helium cryostat. Since the distance between the beam pipe and the helium vessel at 4.5 K is only 3.5 mm, The cryostats are required to have high fabrication accuracy and high thermal performance. The design study of cryostat is on-going.

Table 3: Design parameters of QC1LP and QC1RP.

	QC1LP	QC1RP
Coil inner radius (mm)	22	
Coil outer radius (mm)	27.55	
B'L (T)	22.9	22.4
Field gradient (T/m)	62.0	75.6
Effective length (m)	0.370	0.297
Magnet current (A)	1232	1511
Max. field in coil with solenoid (T)	3.98	3.95
Op. point to Bc at 4.4 K (%)	80	86

Correction Coils for Cancelling QC1 Leakage Fields

Since QC1LP and QC1RP are iron-free magnets, the leakage fields pass also through the neighboring electron beam line. These leakage fields have harmful influences on the beam dynamics of HER and consist mainly of normal dipole, normal quadrupole and normal sextupole field (b_1, b_2 and b_3). In order to cancel out these fields, correction coils of b_1, b_2 and b_3 on the electron beam line are designed. Special shaped corrector coils are required for the cancellation. Figure 3 shows the designed dipole correction coil.

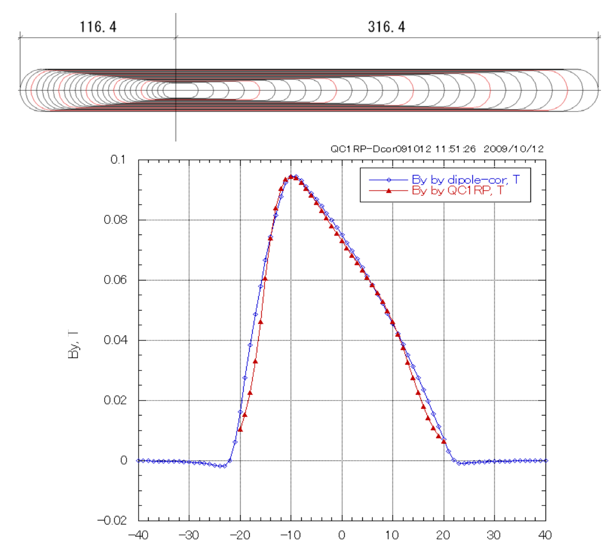

Figure 3: Typical coil shape of the correction coil for cancelling QC1RP leakage fields (up) and field profiles along the electron orbit at QC1RP (down). The red triangle shows the leakage field by QC1RP and the blue circle shows the field produced by this cancel corrector coil (b_1).

QC1LE, QC1RE and QC2RP Magnet

The design concepts of QC1LE and QC1RE are same to QC1RP. The magnet inner radius and the effective length is 28.25 mm and 0.360 m, respectively. The parameters for these magnets are summarized in Table 4. In order to generate the field gradients of 72.4 T/m and 72.9 T/m by QC1LE and QC1RE, the operating currents are designed to 1801 A and 1815 A, and these operation points correspond to 75 % and 76 % of the critical conditions, respectively.

Table 4: Design parameters of QC1LE, QC1RE and QC2RP magnet.

	QC1LE	QC1RE	QC2RP
Coil inner radius (mm)	28.25		41.6
Coil outer radius (mm)	33.8		46.2
B'L (T)	26.0	26.2	10.92
Field gradient (T/m)	72.4	72.9	31.2
Effective length (m)	0.360		0.350
Magnet current (A)	1801	1815	368
Max. field in the coil with solenoid (T)	3 .15	3.28	1.8
Op. point to Bc at 4.4 K (%)	75	76	68

QC2LE, QC2RE and QC2LP Magnet

QC2LE, QC2RE and QC2LP are designed as the Halbach-type permanent magnets [2]. Since these magnets are located behind the cryostat, the cryostat can be small and assembly of the vacuum chamber can be simple. The required remnant field for the permanent material is less than 0.9 T and Samarium-Cobalt was selected due to its reduced sensitivity to radiation. However, extra magnets for these magnets are required to change beam energies. The study of the permanent magnet is ongoing.

Compensation Solenoid

By recent studies of the beam dynamics, the degradation of the vertical emittance due to the fringe fields of the compensation solenoids (CS-L and CS-R) was recognized [1]. In order to reduce these degradation the compensation solenoids are designed to be segmented into small coil pieces as shown in Fig. 4. And the coil pieces have gradually decreasing turns along the distance from IP in order to produce a slow gradient of the solenoid field along the Belle axis. Solenoid field profile along Belle axis is shown in Fig. 5. The peak fields with Belle solenoid, CS-L and CS-R are -3 T and -2.5 T, respectively.

According to these field profiles, the CS-L and CS-R are subject to repulsive electro-magnetic forces against the Belle detector. In order to reduce these forces, inner radii of Belle's end yokes are reduced from 50 cm to 35 cm and attach an additinal iron blocks on the cryostats. Total forces of 16.6 kN for Cryostat-L and 9.4 kN for Cryostat-R are at the same level as that of KEKB CS-L and they will be taken care of in the cryostat and the support structure design.

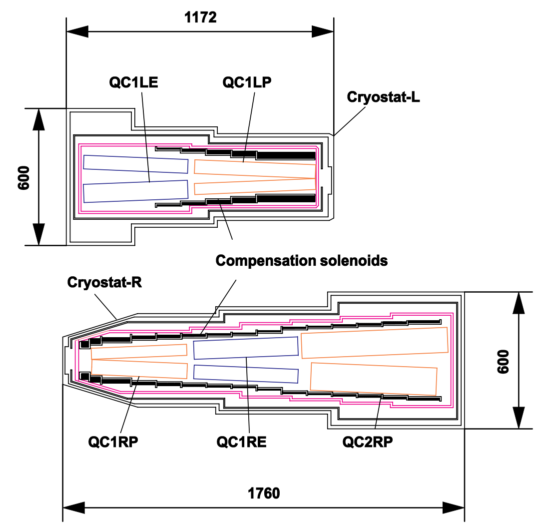

Figure 4: Schematic drawing of compensation solenoids.

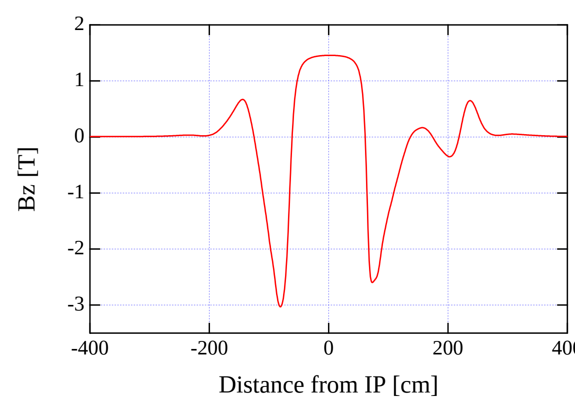

Figure 5: Solenoid field profile along Belle axis from IP.

CONCLUSION

We have performed the design study of the final focus quadrupole magnets for the Super-KEKB interaction region, which based on the nano-beam scheme. By using both type of superconducting and permanent magnets, IR magnet design will be simple. We are studying the manufacturing errors and try to fabricate the R&D magnets for each magnet.

REFERENCES

[1] K. Oide, The 15th KEKB Accelerator Review Committee, `http://www-kekb.kek.jp/MAC/2010/`.

[2] K. Halbach, Nucl. Instru. and meth. 169 (1980) 1.