DESIGN STUDY OF SUPERCONDUCTING FINAL FOCUS QUADRUPOLES FOR THE SuperKEKB INTERACTION REGION

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Abstract

SuperKEKB is an upgrade project of KEKB, which target luminosity is $\sim 10^{36} cm^{-2}s^{-1}$. KEK is studying the design of the final focus quadrupole magnets based on the nano-beam scheme. Two types of magnets have been studied for final focus magnets: Active-shield superconducting quadrupole magnet and permanent quadrupole magnet. In this paper, the conceptual design of the final focusing system and magnets are reported.

INTRODUCTION

Upgrade of KEKB (SuperKEKB) has been proposed. The target luminosity of SuperKEKB is $\sim 10^{36} cm^{-2}s^{-1}$ and the target total integrated luminosity is 50 ab^{-1} by 2020. Two schemes for SuperKEKB design are now being studied: (i) High Current scheme and (ii) Nano-beam scheme. Table 1 shows the basic parameters for each SuperKEKB scheme. By the recent simulation studies about High Current scheme, it is found that the bunch length of low energy ring (LER) may be limited due to a coherent synchrotron radiation effect. This may cause a strong limitation to achieve the target luminosity. We are now trying to design the IR based on Nano-beam scheme. In this paper we describe the design study of the final quadrupole magnets, QC1, for the SuperKEKB interaction region (IR).

Table 1: Basic Design Parameters for each Schemes

	High Current	Nano-beam
E (GeV) (LER/HER)	8/3.5	8/3.5
ϕ (mrad)	0	30
β_x^* (mm)	200/200	44/25
β_y^* (mm)	3/6	0.2/0.4
σ_x^* (μm)	69/60	11/6.3
σ_y^* (μ m)	0.85/0.73	0.07/0.05
σ_z (mm)	5/3	6/6
beam current (A)	9.4/4.1	3.3/1.9
ne	5.3×10^{10}	4.8×10^{10}
np	12×10^{10}	8.4×10^{10}
ε_x (nm)	24/18	2.8/1.6
ε_y (nm)	240/90	23.5/7.4
ν_x/ν_y	0.506 /0.545	0.53/0.56
No. of bunch	5000	2500

IR DESIGN

A schematic layout of the beam lines near the interaction point (IP) is shown in Fig. 1. Two beams cross at the IP with the crossing angle of 60 mrad. The magnet layout is almost symmetrical with respect to the IP. Final vertical focusing is provided by QC1LP and QC1RP for LER beam and QC1LE, and QC1RE for the high energy ring (HER) beam, respectively. QC1 magnets are overlaid with superconducting anti-solenoid magnets. And all of these magnets are placed in the detector solenoid fields at 1.5 T. Final horizontal focusing for each beam is provided by the QC2 magnets. The parameters for the magnets are summarized in Table 2.

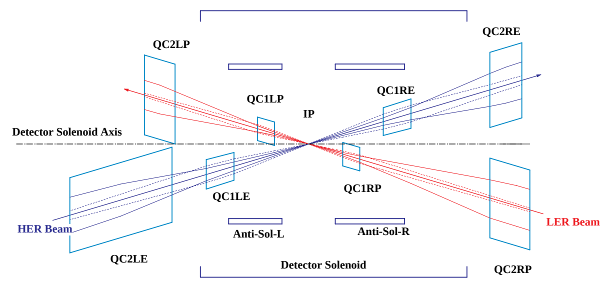

Figure 1: Schematic layout of the beam lines near the IP. The required horizontal and vertical physical apertures are shown by the solid and dashed lines, respectively.

The β functions and the required apertures are shown in table 3. Because (i) the damping ring for both rings will be constructed, (ii) the synchrotron phase space injection scheme [2] will be applied and (iii) the horizontal tune is far from the half integer tune, the required physical aperture is drastically reduced. The required acceptances of 5×10^{-7} (m) for horizontal and 2×10^{-8} (m) for vertical directions are assumed for the beam injection.

Table 2: Positions of the Magnet Center from IP, Length and field Gradients

Magnet	Z (m)	L (m)	G (T/m)	focus
QC2LE	-3.48	2.0	6.4	Horz. e^-
QC2LP	-2.78	0.6	10.8	Horz. e^+
QC1LE	-1.66	0.52	49.3	Vert. e^-
QC1LP	-0.80	0.32	61.0	Vert. e^+
QC1RP	0.80	0.32	56.4	Vert. e^+
QC1RE	1.66	0.52	46.4	Vert. e^-
QC2RP	3.70	0.6	4.4	Horz. e^+
QC2RE	3.70	0.6	19.0	Horz. e^-

QC1 MAGNET DESIGN

QC1 magnets have to meet the following specifications: (1) The conductor and the cryostat space should be minimized because the beam separation between HER and LER

Table 3: β functions and the required apertures. $\beta_x^*/\beta_y^* = 20/0.2(mm)$ is assumed in this table.

Magnet	β_x (m)	β_y (m)	Inj x (mm)	Inj y (mm)
QC2LE	1809	4368	30.1	9.35
QC2LP	1462	640	27.0	3.58
QC1LE	1.46	0.52	4.8	9.6
QC1LP	0.91	0.32	5.8	7.8
QC1RP	0.91	0.32	5.8	7.8
QC1RE	1.46	0.52	4.8	9.6
QC2RP	2920	674	38.8	3.5
QC2RE	2280	3917	33.8	8.9

is less than 48 mm. (2) The large aperture with good field quality is required. (3) The leakage fields for the beam of the other ring should be minimized. We are studying two types of QC1 magnets: active-shield superconducting quadrupole magnets [1] and halbach type permanent quadrupole magnets [3].

Active-Shield Superconducting Quadrupoles

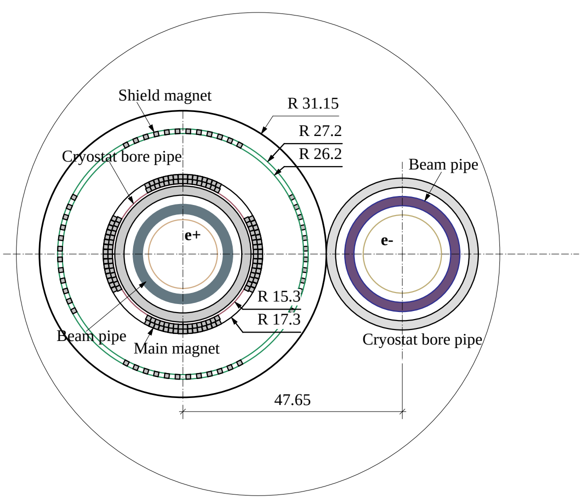

Figure 2: Cross section of QC1RP in the front end.

The QC1RP is designed as the active-shield quadrupole in a conical shape because the distance between two beams at the front end of the magnet is 47.7 mm while that is 61.4 mm at the rear end. The cross section of the QC1RP in the front end is shown in Fig. 2. The main magnet consists of two layer coils, and the field gradient of the magnet is calculated to be 103.0 T/m at 1288.6 A. The leak field on the electron beam by the magnet is 0.052 T. The shield magnet consists of one layer coils of 6 turns. This magnet is designed to be operated in the opposite current direction in order to eliminate the leak field on the electron beam, but on the other hand the quadrupole component on the positron beam is decreased, too. The shield magnet at 1288.6 A decreases the leak field to 3×10^{-4} T with decreasing the field gradient from 103 T/m to 88.4 T/m. The magnetic field

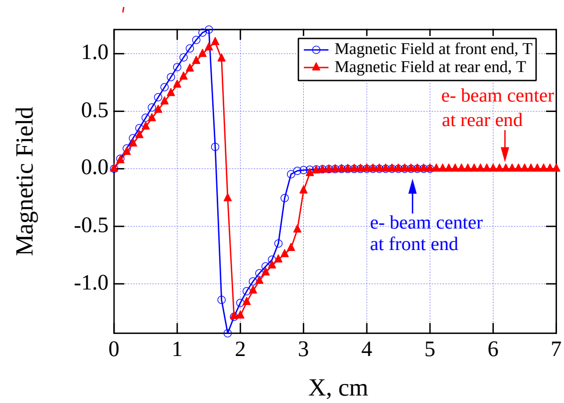

Figure 3: Magnetic field profiles in the horizontal axis. The position of X=0 corresponds to the center of QC1RP.

Table 4: Magnet Parameters for QC1RP

Main Coil	Two layers
Inner radius (front / rear end)	15.3 mm / 16.97 mm
Outer radius (front / rear end)	17.3 mm / 18.97 mm
Turn number/pole	16
Shield Coil	One layer
Inner radius (front / rear end)	26.2 mm / 29.05 mm
Outer radius (front / rear end)	27.2 mm / 30.05 mm
Turn number/pole	6
Magnet as QC1RP	
S.C. cable / cable size	NbTi / 1mm 1mm
S.C. cable Cu ratio	1.2
Operation current	1288.6A
Field gradient (front / rear end)	88.35 T/m / 72.95 T/m
Effective magnetic length	0.2238 m
Maximum field in the coil	1.43 T
Operation temperature	4.4 K

profiles along the horizontal axis at both ends are shown in Fig. 3. In the rear end, the field gradient is 72.95T/m and the leak field is 4.5×10^{-4} T. The magnet parameters are listed in Table 4.

The cross section of QC1RE is shown in Fig. 4 . The magnet is designed as a cylindrical shape because the distance of two beams is 83.6 mm at the front end of this magnet and this distance is sufficient for designing this magnet as the cylindrical type. The field gradient of the main magnet at 1060.6 A is calculated to be 100.35 T/m, and with the shield magnet, the field gradient of QC1RE is 70.0 T/m and the leak field on the positron beam is 7.2×10^{-4} T.

The operating points for these magnets under the solenoid field of 1.5 T are evaluated as shown in Fig. 5. The current densities for QC1RE and QC1RP are 2881 A/mm^2 and 3500 A/mm^2, respectively, and the both magnets are designed to be operated at 85 % with respect to the critical points.

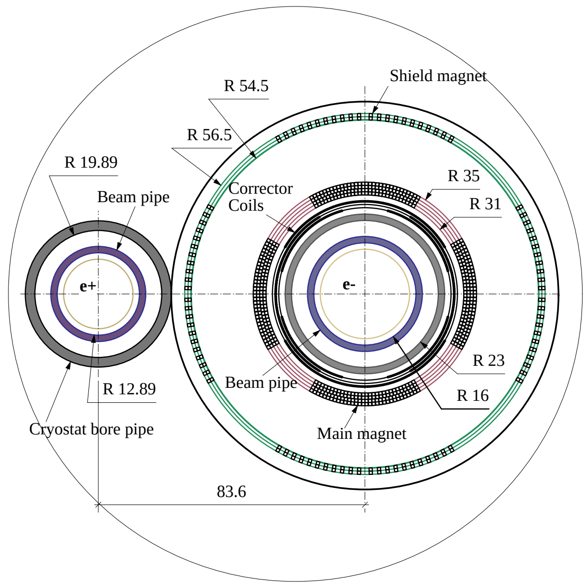

Figure 4: Cross section of QC1RE.

Table 5: Magnet Parameters for QC1RE

Main Coil	Four layers
Inner / Outer radius	31.0 / 35.0 mm
Turn number / pole	62
Shield Coil	Two layers
Inner / Outer radius	54.5 / 56.5 mm
Turn number / pole	22
Magnet as QC1RE	
Operation current	1060.6A
Field gradient	70.0 T/m
Effective magnetic length	0.3450 m
Maximum field in the coil	2.34 T
Operation temperature	4.4 K

Permanent Quadrupoles

A Halbach type permanent quadrupole is another choice for QC1 magnets. Sm_2Co_{17} (Br=1.1 T) is selected as the permanent magnet material. The tapered quadrupole magnet is designed for QC1RP, which is shown in Fig. 6-(a). QC1RE are designed as a cylindrical shape. The parameters for the permanent magnets are shown in Table 6. The magnetic field profiles along the horizontal axis at both ends are also shown in Fig. 6-(b). The QC1LP and QC1LE have a similar shape to QC1RP and QC1RE, respectively.

Table6: Physical Dimensional Parameters for Permanent QC1RP and QC1RE Magnets

	r1 (mm)	r2 (mm)	L (mm)	G (T/m)
QC1RP-1	12	18	50	55.8
QC1RP-2	12	21	100	71.9
QC1RP-3	12	28	100	96.0
QC1RE	20	55	400	65.8

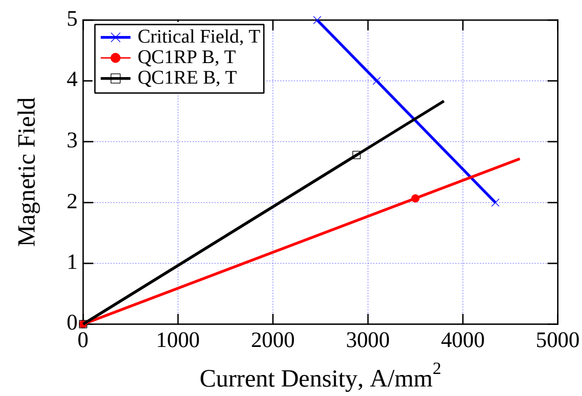

Figure 5: Load lines of QC1RP and QC1RE with the solenoid field of 1.5 T.

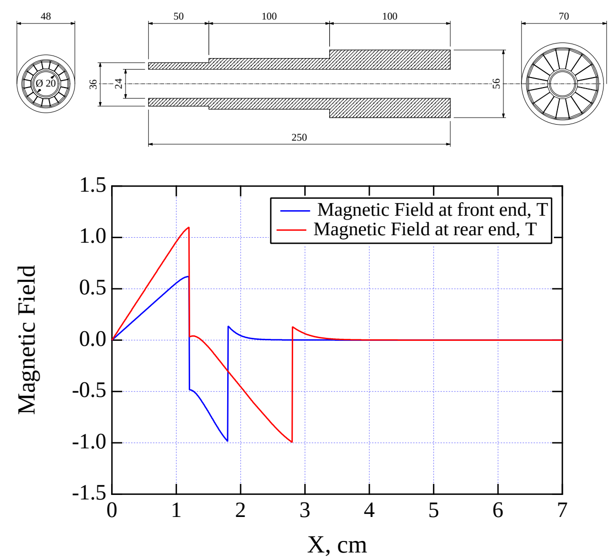

Figure 6: (a) Tapered permanent quadrupole magnet of QC1RP and (b) Magnetic field profiles, respectively.

CONCLUSION

We have performed the design study of the final focus quadrupole magnets for the SuperKEKB IR based on the nano-beam scheme. The final focus magnets, QC1 magnets are feasibly designed as two types of an active-shield superconducting quadrupole magnet and a permanent quadrupole magnet. As the next step, we will study the magnetic field quality and manufacturing errors of the both types.

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