DYNAMIC APERTURE WITH MULTIPOLES OF SPECIAL MAGNETS IN THE KEKB INTERACTION REGION

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Abstract

At KEKB, six quadrupoles of special shapes are placed in the interaction region. Those quadrupoles are accompanied by higher-order multipole components which are prominent sources to degrade the dynamic aperture, and which even affect the linear optics because the design orbit passes through one of the special quadrupoles off-axis. In order to represent realistic field distributions of those quadrupoles obtained by hardware design, we take the higher-order multipoles up to 21st into account in our simulation. Using this model, we have redesigned the linear lattice and have estimated tolerances on the magnitudes of multipole components.

1 INTRODUCTION

KEKB[1] is an 8 GeV + 3.5 GeV electron-positron double-ring collider with small vertical beta function at the interaction point (IP) ($\beta_y^* = 1\mathrm{cm}$) and short bunch spacing (59 cm). In order to separate both beams, a finite beam crossing angle of 22 mrad is adopted, and eight special quadrupole magnets listed in Table 1 are installed near IP. Two final-focus quadrupoles are superconducting magnets which work on both beams. The other six are iron-core magnets with special shapes to let the counter-rotating beam pass through unaffectedly.

Magnet	r_b (mm)	B' (T/m)	x_{max} (mm)	y_{max} (mm)	Beam
QC2LE	60	3.2	67.5	13.3	$e^- \downarrow$
QC2LP	40	6.1	56.9	10.2	$e^+ \uparrow$
QC1LE	38	-14.2	22.4	20.7	$e^- \downarrow$
QCSL (IP)	(75)	-21	13.3	19.9	$e^- \downarrow e^+ \uparrow$
QCSR	(75)	-21	14.2	24.3	$e^- \downarrow e^+ \uparrow$
QC1RE	70	-13.2	28.5	26.6	$e^- \downarrow$
QC2RP	45	2.9	68.6	11.9	$e^+ \uparrow$
QC2RE	60	10.8	69.2	16.3	$e^- \downarrow$

Table 1: Special quadrupole magnets near IP. In the first column, r_b is the bore radius, B' the field gradient, x_{max}andy_{max} the maximum amplitudes of the injected beam in the horizontal and vertical planes. The positive sign of B' means horizontal-focusing.

In spite of the small beta function, a chromaticity correction scheme with noninterleaved sextupoles[2] provides a large dynamic aperture for the bare lattice of KEKB. After canceling main transverse nonlinearity of sextupoles, the dynamic aperture is limited by small residual terms such as the nonlinear Maxwellian fringe field of final quadrupoles. The iron-core quadrupoles near IP accompany higher-order multipole components which may degrade the dynamic aperture. In this paper, we discuss how to treat the multipole components and examine their effects on the beam dynamics mainly in the high-energy ring (HER), because HER is strongly affected by the multipoles of the vertical-focusing quadrupoles named QC1LE and QC1RE placed next to the superconducting ones.

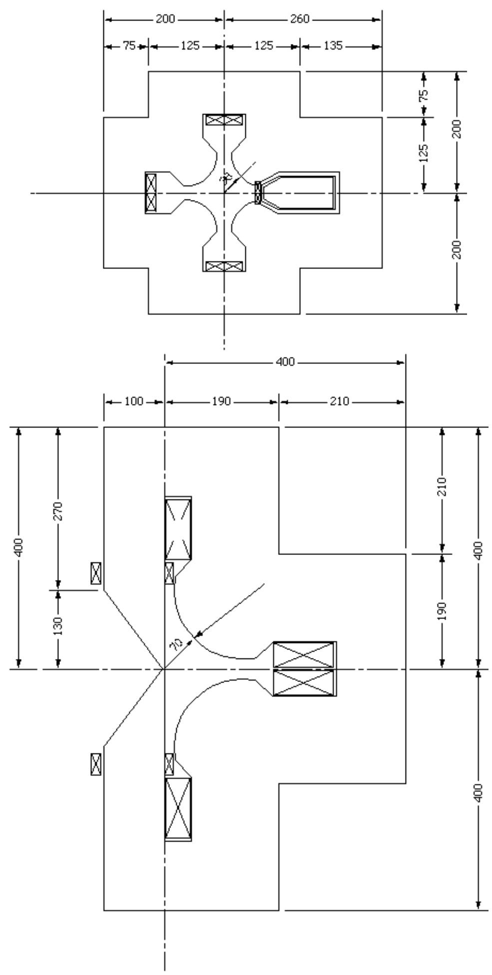

Figure 1: Schematic view of QC1LE (above) and QC1RE (below). A field free space is embedded in QC1LE. The other four quadrupoles have shapes like QC1LE.

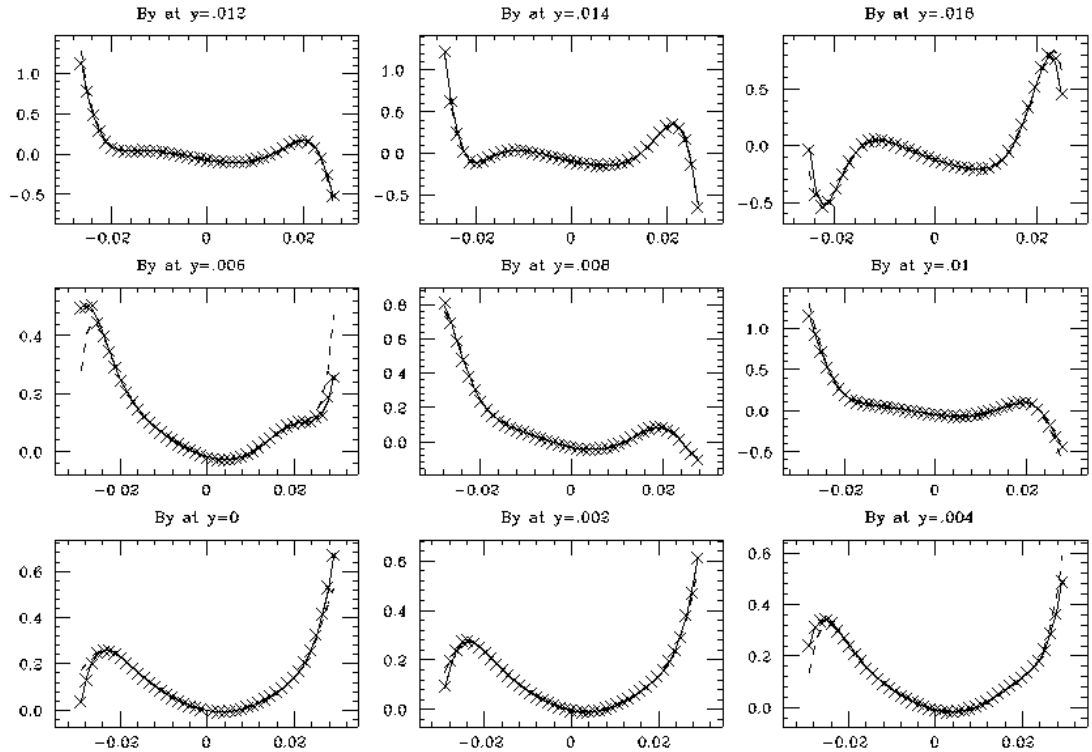

Figure 2: A part of the fitting results of the QC1LE multipoles. The crosses show the data obtained by OPERA-2d. The solid and dashed lines depict the fitting results with the multipoles up to $n = 21$ and 14, respectively. The dashed line deviates from the data near the edge of the fitting region ($x^2 + y^2 < (0.03)^2$). Each graph collects the data at $y = constant$. The horizontal axis is the horizontal position x in meter, and vertical axis is the B_y in Gauss, respectively.

2 MULTIPOLE EXPANSION

The six iron-core quadrupoles have been designed based on two-dimensional field calculations by OPERA-2d[3]. One of the quadrupoles, QC1RE, is a half quadrupole, and the rest are full quadrupoles with field free space for the counter-rotating beam as shown in Fig. 1. In order to derive the multipole components, we express the magnetic fields, B_x and B_y as

$$B_y(x, y) + iB_x(x, y) = B_0 \sum_{n=0}^{N} (b_n + ia_n)(x + iy)^n. \quad (1)$$

After subtracting the main quadrupole component, the data B_x and B_y obtained by the OPERA-2d calculation are fitted in the standard least-square method with parameters b_n in the region which covers the physical aperture. The skew components a_n are set to be zero since all the quadrupoles have symmetry with respect to the horizontal median plane.

Figure 2 shows an example of fitting for QC1LE. Introducing b_n up to $n = 21$, the field data at 537 points are represented well with the residuals smaller than 0.1 Gauss which is consistent to the estimated errors in the field calculation. The other five quadrupoles are also fitted with the same accuracy in the same way. The merit of this fitting method is to fully utilize the field data over the region where the beam may exist. All calculations concerning the data fitting in this section, and optics matching and tracking in the next section have been done by the code SAD[4] developed at KEK.

3 EFFECTS ON DYNAMIC APERTURE

To estimate the effect of the multipoles, at the first step, we compare the dynamic aperture with and without the multipoles of QC1LE out of the four special quadrupoles in HER. Since the design orbit passes through QC1LE on-axis, we need not redesign the linear optics even when the multipoles are included. (The design orbit also lies on-axis in the horizontal-focusing full quadrupoles.) The strengths of sextupoles are also not reoptimized with the multipoles.

The dynamic aperture has been estimated by six-dimensional full-symplectic tracking using SAD. The $2(n + 1)$-pole magnets up to $n = 21$ with a finite effective length are treated consistently in SAD. Each magnet is subdivided into many pieces along the beam axis. The number of pieces is increased until the results of tracking converge. The nonlinear Maxwellian fringe field at the edge of the magnet is also involved in the tracking not only for the main quadrupole but for the multipoles.

As shown in Fig. 3(a), the multipole components drastically decrease the transverse dynamic aperture near the on-momentum region. The dynamic aperture at QC1LE is $(x, y) = (2.9\text{cm}, 2.7\text{cm})$ which is a few mm larger than

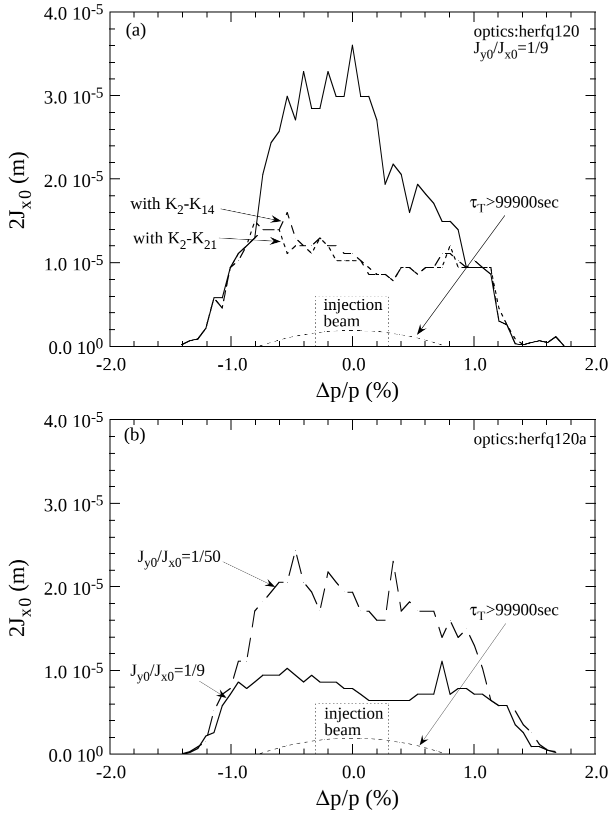

Figure 3: Dynamic aperture of HER with the multipole components of special quadrupoles. (a) with (dashed lines) and without (solid line) the multipoles of QC1LE. (b) with the multipoles of all the special quadrupoles.

the physical aperture. This result is reasonable since the magnetic field is cared only inside the physical aperture in the magnet design, thus it deviates rapidly from the ideal quadrupole outside the physical aperture. The two types of multipole expansion up to $n = 14$ and $= 21$ do not make a significant difference in the dynamic aperture.

In the next step, we take the multipoles of all special quadrupoles including QC1RE into account. Because the design orbit goes through QC1RE at 44.55 mm off-axis, we must redesign the linear lattice with the multipoles of QC1RE and must readjust the strengths of the sextupoles as well. Figure 3(b) shows the dynamic aperture with the multipoles of all special quadrupoles. The dynamic aperture decreases again compared with Fig. 3(a), but still satisfies the requirement for beam injection ($2J_{x0} = 6 \times 10^{-6}\mathrm{m}$ at the momentum deviation of $\pm 0.3\%$) and is cocsistent with the the physical aperture at QC1RE as shown in Fig. 4. We assume the vertical-to-horizontal coupling of the coherent oscillation at injection J_{y0}/J_{x0} to be 1/9 in the tracking.

In the case of a smaller coupling ($J_{y0}/J_{x0} = 1/50$), the dynamic aperture is improved considerably beyond the physical aperture as shown in Figs. 3(b) and 4.

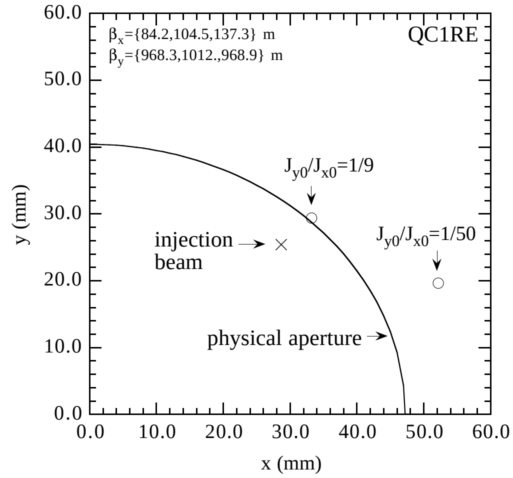

Figure 4: Physical and dynamic apertures at QC1RE. The origin is set at 44.55 mm from the center of QC1RE.

4 CONCLUSIONS

The iron-core quadrupoles with special shapes near IP have been designed by the two-dimensional field calculation. The magnetic field distributions of those quadrupoles have been expressed well with the higher-order multipole components up to 21st over the range which covers the physical aperture. Although the dynamic aperture of HER has been drastically degraded by those multipoles, it is still larger than the physical aperture at QC1LE and QC1RE, and satisfies the requirement for beam injection.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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

[2] K. Oide and H. Koiso, Phys. Rev. E47, 2010(1993). H. Koiso and K. Oide, Proc. 1995 Part. Accel. Conf. at Dallas, TAG11, 2780(1995).

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

[4] Information on SAD is available at http://www-acc-theory.kek.jp/SAD/sad.html.