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DIPOLE QUADRUPOLE MAGNET DESIGN FOR KOREA-4GSR*

H. S. Suh†, D. E. Kim, H. G. Lee, I. W. Chun, S. H. Jeong, Y. G. Jung
Pohang Accelerator Laboratory, POSTECH, Korea

Abstract

As multipurpose synchrotron radiation facilities, the Korea-4GSR is being promoted in Korea from July 2021 to the end of 2027. The construction project includes linac, 4 GeV booster, and storage ring. The circumference of the storage ring is about 800 meters, the beam emittance is 58 pm.rad, and there are more than 40 beamlines with 28 superperiods. A large number of electromagnets are used in these facilities. This presentation describes the design of the dipole quadrupole (DQ) magnets used in the storage ring. The DQ magnets are basically offsetted standard quadrupoles for design simplicity. The poles are optimized for minimum harmonic content and maximum B' with tapering. All DQ magnets should have trim coils for dipole component that will be used to keep the dipole field while quadrupole field changes.

INTRODUCTION

Korea-4GSR has many electromagnets and various devices. For efficient use of space, there are dipole quadrupole (DQ) magnets that functions as a quadrupole magnet and a dipole magnet. The shape of this magnet is the same as that of the conventional quadrupole magnet, but the electron beam is not incident to the center of the magnet, but is incident to the offset point in the transverse direction from the center of the magnet, so the dipole field as well as the quadrupole field affects the electron beam. In the DQ magnet, the electron beam is focused or defocused by the quadrupole field, and curved or reverse curved by the dipole field.

DIPOLE QUADRUPOLE MAGNET

There are 4 types of DQ magnets to be used, and 56 of each type are used, so a total of 224 DQ magnets are needed [1]. In this paper, the design details of the DQ51 and DQ52, which have a relatively large core length, are explained. The poles of these two magnets form a curve according to the electron beam, and the return yokes have a rectangular shape without a curve. Currently, the position and the size of the photon slot have not been determined, so this design is designed without the photon slot, and later the design must be modified to include the photon slots. And since all DQ magnets use their own power supply, electrical characteristics must be considered in the design process.

Requirements from Beam Dynamics

The Aperture radii of the two magnets DQ51 and DQ52 are different from 30.0 mm and 15.0 mm, so most requirements for the two magnets are different. The beam dynamics requirements of the DQ51 and DQ52 are shown in Table 1. The good field radius, field gradient, and dipole strength are all values at offset Δx. The DQ51's dipole field strength is positive, while the DQ52's strength is negative, the DQ52 has a reverse bending function and the pole's curve direction is opposite to that of the DQ51. Both ends of the magnet core are parallel to each other, so the overall shape of the magnet is square. The square-shaped core has the characteristic that the multipole components are generated more at the end of the magnet.

Table 1: Requirements for DQ51 and DQ52

Parameter	DQ51	DQ52
Aperture radius [mm]	30.0	15.0
Good field radius [mm]	15.0	7.0
Field gradient B' [T/m]	28.05	49.76
Dipole field [T]	0.565	-0.166
Effective length [mm]	820.0	626.0
Bending angle [deg]	1.988	-0.446
Offset Δx [mm]	20.136	3.337
Relative multipole components		< 1.0E-3

The requirement for the relative multipolar component at the electron beam position is less than 1.0E-3. With the electron beam stored in the storage ring, the quadrupole field strength can vary in the range of 95 to 105% of the nominal value. Even if the quadrupole magnetic field changes, there is a condition that the strength of the dipole magnetic field must be constant. To satisfy this condition, trim coils must be prepared for all DQ magnets.

Magnetic Field Distribution

Software OPERA/TOSCA 2D/3D was used as a magnetic field calculation code [2], The BH-table of low carbon steel DT4C, which is generally easy to obtain, was used. Considering the symmetry of the electromagnet, only ¼ part of the magnet was modelled. Figure 1 shows the magnetic field distribution of the DQ51 and DQ52 magnets.

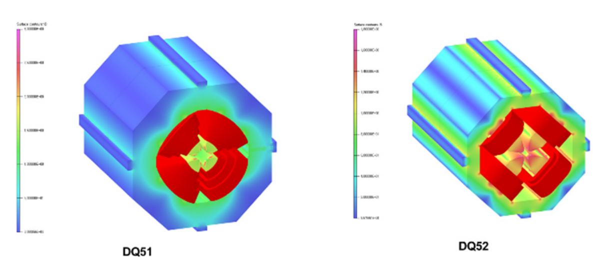

Figure 1: Magnetic field distribution of DQ51 and DQ52.

* This work is supported by the Ministry of Science and ICT of Korea.
† suhhs@postech.ac.kr

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Main Parameters

The electromagnet can be used for a long time by maintaining the appropriate coil temperature while satisfying the magnetic field requirements. The coils were densely packed to increase the magnetic efficiency and reduce the size of the electromagnet. In order to use a general power supply device, the electrical characteristics were determined without special electrical parameters. Overall, the pole is symmetrical to the left and right for easy production and management, and the core shape is designed simply. The main designed parameters are shown in Table 2. The size of the trim coil is 2.2 × 4.4 mm^2 for both magnets.

Table 2: Main Parameter of DQ51 and DQ52

Parameter	DQ51	DQ52
Core length [mm]	801.4	615.0
Current [A]	228.86	102.89
Current density [A/mm^2]	3.78	3.24
Resistance [Ohm]	0.12	0.17
Voltage [V]	28.43	17.32
Power [W]	6506	1782
Coil size [mm^2]	9.0×9.0(ϕ5.0)	6.5×6.5(ϕ3.5)
Coil turn per pole	42	44
Temperature rise [K]	15	9
Mass [kg]	4043	745

Core and Coil Shape

The poles are tapered to increase the magnetic field strength. For stable installation, the thickness of the return yoke is thickened to widen the bottom surface of the magnet. Figure 2 the cross-section of the core and coil of the DQ51 and DQ52 showing 1/8 of the entire core and coil. The pole part is curved according to the electron beam curve, but the return yoke part is rectangular for convenience of manufacture and installation. In addition to the beam dynamics requirements, the gap between adjacent poles, the gap between adjacent coils, and the size of the photon slot must be considered during the magnet design process.

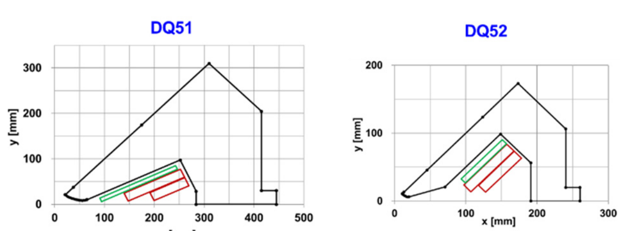

Figure 2: Cross-section of core and coil of the DQ51 and DQ52 (green line: trim coil, red line: main coil).

Among the lines representing the coils in the Fig. 2, the green line represents the auxiliary (trim) coil and the red line represents the main (quadrupole) coil. The trim coils are located close to the pole because the effect of the dipole field control by the trim coil is very weak. Depending on the pole shape, the DQ51 coil has a truncated cone shape and the DQ52 coil has a racetrack shape. The pole shape of the two magnets is curved according to the electron beam curve, but both coils are designed to be straight for ease of manufacture. A hollow conductor using cooling water was used to stabilize the temperature of the coil (see Table 2).

Pole Tip Shape and Multipole Components

The electron beam does not pass through the center of the DQ magnet, but passes through the lateral offset point, nevertheless the pole of the DQ magnet is simply designed symmetrically. Figure 3 shows the shape of a half pole tip of the DQ51 magnet. In the figure, the pole tip line is composed of four segments, a-b, b-c, c-d, and d-e, and each line segment is composed of several small segments. It was decided to minimize the magnetic multipole component by adjusting the length and slope of each small segment.

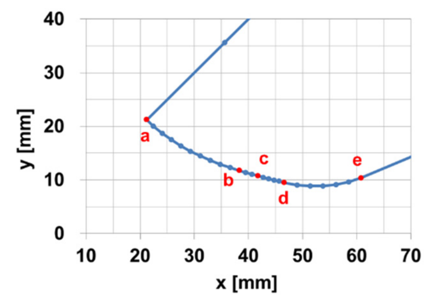

Figure 3: A half pole tip shape.

First, the core cross-section was optimized to sufficiently satisfy the magnetic multipole component requirements with the 2D code. In the 2D code, the offset Δx position through which the electron beam passes is modelled as the origin. In this way, it is convenient to calculate the magnetic multipole component. In the 3D model, the pole is curved in the same way as the orbital curvature of the electron beam, and the return yoke shape is designed in a rectangular shape without a curve, making it easy to manufacture, install, and manage. Chamfers were added to pole posts and pole tips.

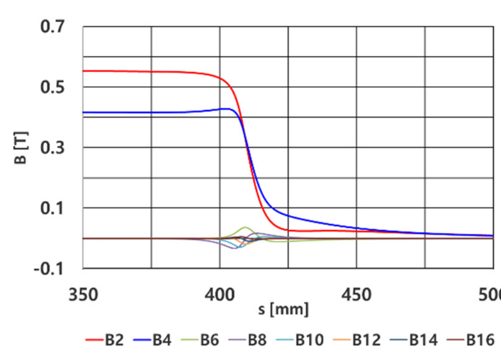

Figure 4: Multipole component distribution of the DQ51 (B2: dipole, B4: quadrupole, B6: sextupole, and so on).

Figure 4 shows the distribution of magnetic multipole components of the DQ51 according to the electron beam

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trajectory. In Table 3 and 4, the values of the 2D/3D relative multipole component are expressed numerically. The 3D multipole components are the results calculated according to the electron beam trajectory at the offset position from the center of the magnet. Pole width and length, pole taper length and angle, chamber size and angle are the factors that affect the magnetic multipole composition and the effective magnetic length.

Table 3: Relative multipole components of the DQ51

Bn/B4	2D	3D
B6/B4	8.13E-05	1.84E-04
B8/B4	1.03E-04	-6.68E-04
B10/B4	9.99E-05	-8.69E-04
B12/B4	8.08E-05	-4.80E-04
B14/B4	5.63E-05	-3.56E-05
B16/B4	3.49E-05	1.30E-04
B18/B4	2.01E-05	1.04E-04
B20/B4	8.91E-06	4.96E-05

Table 4: Relative multipole components of the DQ52

Bn/B4	2D	3D
B6/B4	-3.60E-05	-1.78E-04
B8/B4	-6.44E-05	-2.16E-04
B10/B4	-1.93E-05	-2.31E-04
B12/B4	-1.25E-04	-2.17E-04
B14/B4	-2.14E-04	-2.16E-04
B16/B4	-2.41E-04	-2.05E-04
B18/B4	-2.01E-04	-1.28E-04
B20/B4	-1.56E-04	-5.75E-05

As the number of nodes in the models increases in the OPERA/ TOSCA code, the multipole component tends to decrease, and the effective magnetic length tends to decrease. It's getting closer and closer to the true value.

Magnetic Field vs. Current

Figure 5 shows the change of the quadrupole field according to the increase in current. In the case of DQ51, the temperature rise of the coil is 15 K, and in the case of DQ52, it is 9 K at the nominal current, all of which are stable.

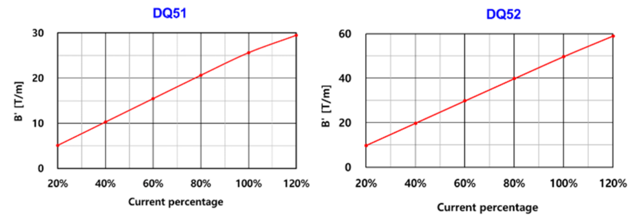

Figure 5: Quadrupole field vs. Current.

There is a possibility that the quadrupole field of the DQ magnets may be changed within the range of 95~105% while an electron beam is stored in the storage ring. At this time, the dipole field must be kept constant. The trim coil is used to satisfy this condition. The trim field changes not only the dipole component but also the quadrupole component value. By numerically calculating the influence constants of each coil on the dipole and the quadrupole fields, and repeatedly calculating the expected magnetic field in the spreadsheet software several times using these constants, the expected final current of each coil can be found. It is an inevitable result that the symmetry of the magnetic field is disturbed by the trim coil field, resulting in an increase in the multipole component.

CONCLUSION

Dipole quadrupole (DQ) magnets are electromagnets that have a quadrupole field and a dipole field as the electron beam passes through an offset point in the transverse direction. We tried to design more efficiently while satisfying the requirements of beam dynamics. Since it is not in the final stage of the design yet, there is a possibility that the design will be modified a little in the future.

REFERENCES

[1] Korea-4GSR CDR, April 2021.

[2] Software, OPERA/TOSCA of Dassault, https://www.3ds.com/products-services/simulia/products/opera/