Design and optimization of combined-function quadrupole-sextupole magnets

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Introduction

A lightweight superconducting (SC) gantry with large momentum acceptance is under development at Huazhong University of Science and Technology (HUST). Three types of quadrupole-sextupole (QS) magnets magnets are used to suppress the chromatic dispersion for the large momentum acceptance. The pole shaping method and the asymmetric excitation method are adopted to achieve the high and adjustable sextupole to quadrupole (S/Q) field ratio. The harmonics of the magnets were optimized to be below 1.0E-03. In addition, we investigate the magnetic center shift, when the S/Q ratios changes.

Method

➢ ***Pole shaping method***

The pole face profile of a combined-function magnet is a superposition of quadrupole and sextupole magnet potentials. The pole face of the magnets can be expressed as:

$$V(r,\theta) = C_2 r^2 \sin(2\theta) + C_3 r^3 \sin(3\theta)$$

➢ ***Asymmetric excitation method***

The adjustment of the sextupole field can be accomplished via the asymmetric excitation method without influence on the quadrupole component. Fig.2 shows the set of the asymmetric current.

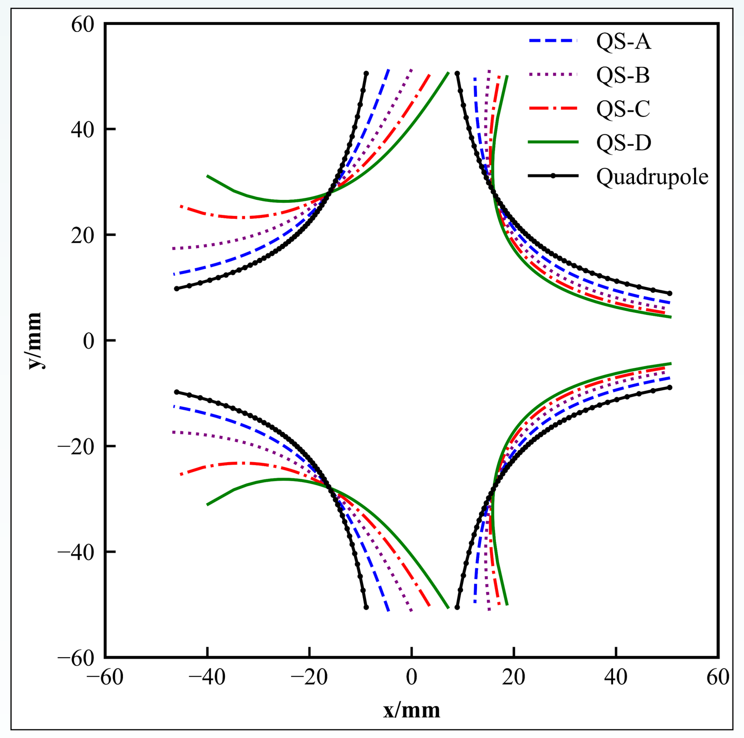

Fig.1 The pole face of the QS magnets with different field ratios.

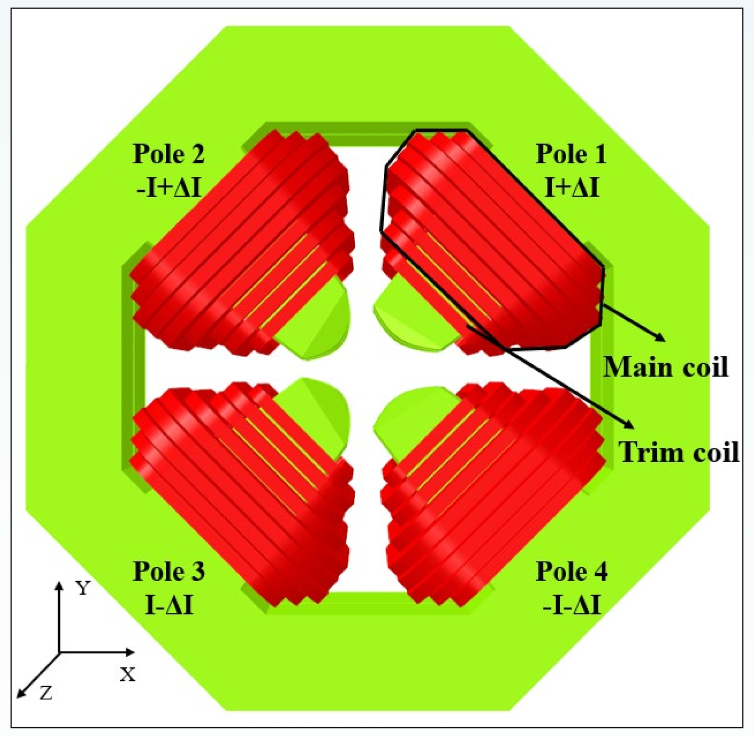

Fig.2 3D simulation model of the QS2 magnet with trim coils to apply the asymmetric excitation.

Result

➢ ***Optimization of the harmonics***

A 2D simulation was developed. For harmonic components beyond the tolerance, the Cn coefficients were chosen to optimize the pole face. The multipole components are lower than 6.5E-04. Then, a 3D simulation was developed. A chamfer at the pole end was used to optimize the harmonics of integral field and reduce the saturation of the pole end. Due to the edge effect, the harmonics of the integral field deteriorate. The Cn coefficients can be adjusted according to the harmonics of the fringe field to reduce the integral field harmonics. The multipole components are lower than 8.2E-04.

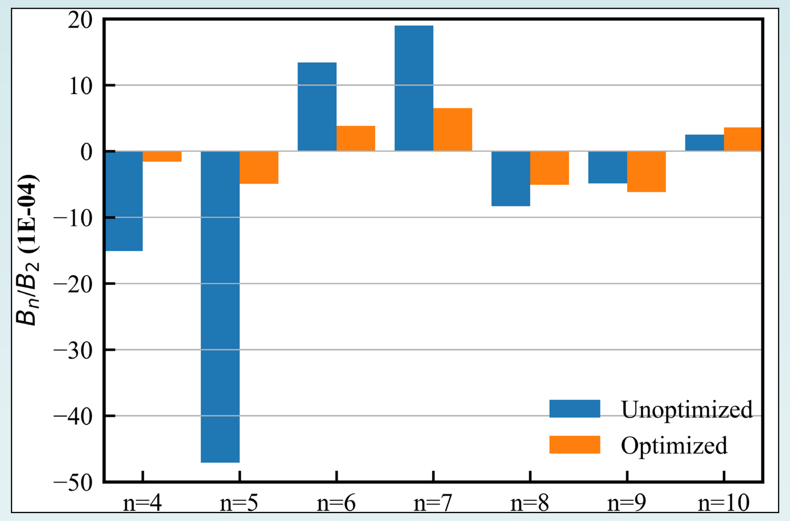

Fig.3 Mutipole components after optimization in the 2D simulation.

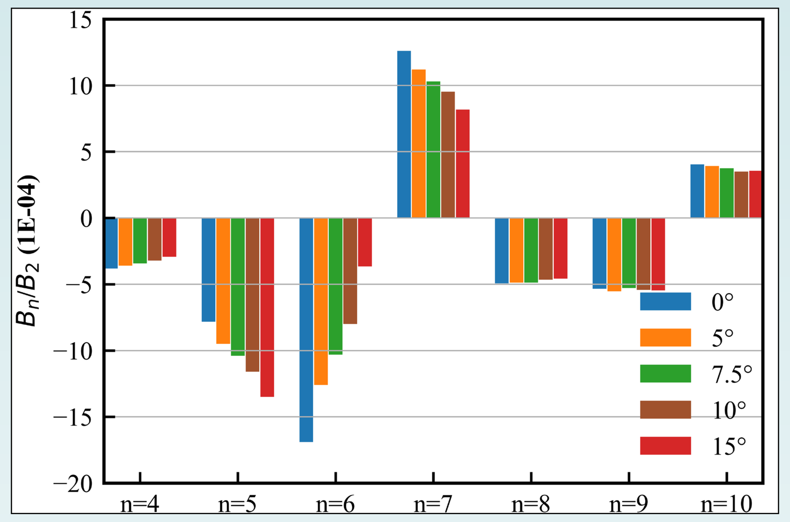

Fig.4 Mutipole components for a chamfer of different angles. A 7.5° chamfer was chosen.

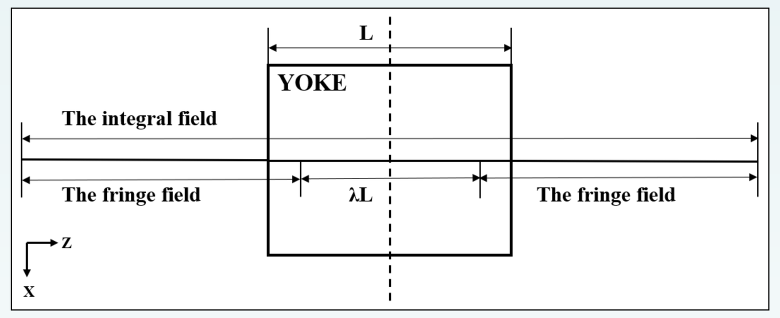

Fig.5 The fringe field region is determined by the harmonic analysis with different values of λL. λ is 0.8 for QS2.

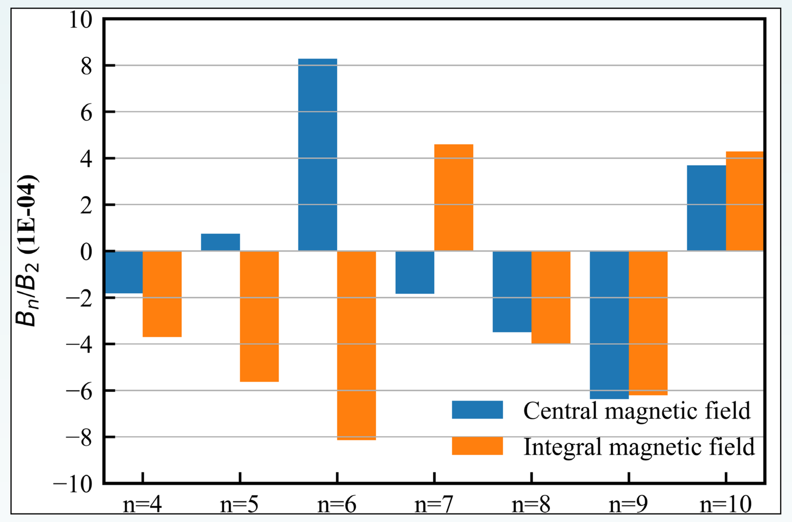

Fig.6 Mutipole components after 2D and 3D optimizations.

➢ ***Simulation with an asymmetric excitation***

The adjustment of the sextupole field can be accomplished via the asymmetric excitation method. The field ratio changes linearly with the asymmetric current in the trim coils. Moreover the asymmetric excitation also causes a dipole field in the Y-direction, and the magnetic center would shift along the X-direction. The results shows good agreement with the theoretica values.

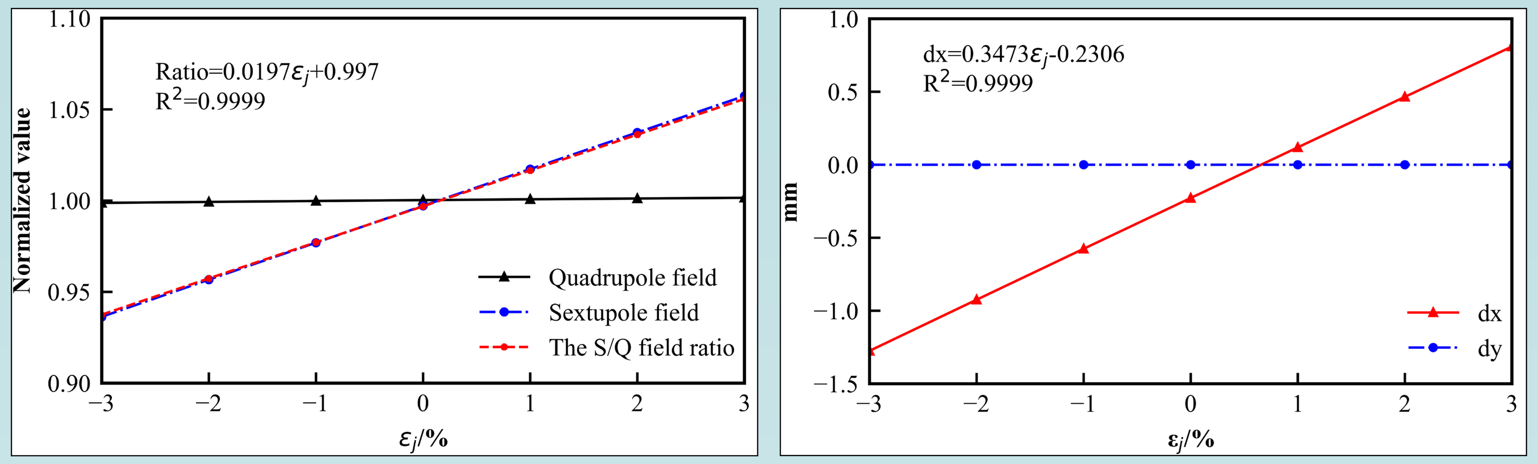

Fig.7 Simulation with an asymmetric excitation : (Left) the adjustment of the S/Q ratio; (Right) the center offset.

➢ ***QS3 magnet***

Since the ratio of the QS3 magnet is 0.333 (exceeding the limit), 8% asymmetric exciting current is adopted. The deviation between the magnetic center and the mechanical center was -6.94 mm. Furthermore, the asymmetric excitation would deteriorate the magnetic field quality (exceeding 4.5E- 03).

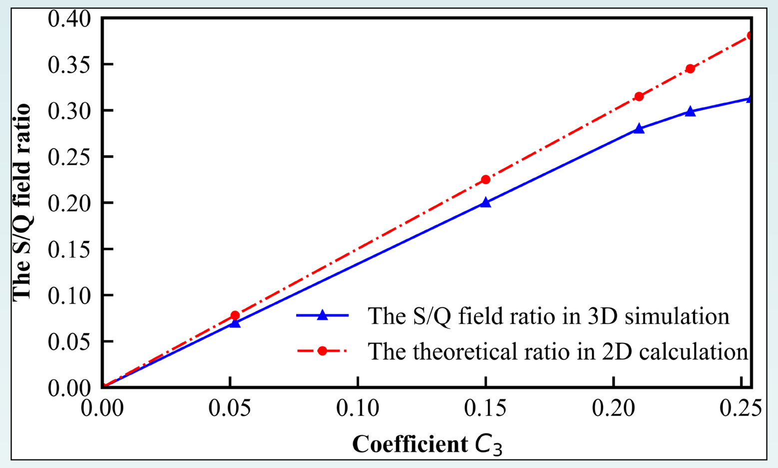

Fig8 The change in the S/Q field ratio as a function of the coefficient C_3.

Conclusion

A relatively high S/Q field ratio with a certain adjustment range can be achieved through the pole shaping and trim coils with the asymmetric excitation. The simulation results show that the sextupole components can be adjusted linearly with no influence on the quadrupole components. To minimize the integral field harmonics, the pole face shimming method on the basis of the harmonic analysis for the fringe field are proposed. The multipole components are optimized to be below 1.0E-03. In addition, a limitation of the pole shaping method is discussed. When the field ratio exceeds 0.28, the QS magnets should be designed carefully.

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