**INTRODUCTION**

- In November 2018, CEPC Conceptual Design Report (CDR) was announced. To pursue higher collision luminosity, accelerator physicists proposed CEPC high-luminosity program.
- The superconducting quadrupole magnet QD0 in CEPC CDR is divided into two superconducting quadrupole magnets Q1a and Q1b. The superconducting quadrupole magnet Q1a was moved forward to a position 1.9 m from the interaction point.
- The double-aperture superconducting quadrupole magnet Q1a is closest to interaction point, making it the most difficult to design.

**PURPOSE**

- According to the design requirements of the single-aperture magnet Q1a, we complete the preliminary physical design based on cos20 coil, racetrack coil and CCT coil.
- Discuss the advantages and disadvantages of the three different coil structures.
- Complete the electromagnetic design of the double-aperture superconducting quadrupole magnet Q1a.
- Optimize the weight of superconducting magnet with the goal of reducing double-aperture magnetic field crosstalk.

**CONTACT**

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**METHOD**

**Cos20 coil structure**
- Two-layer cos20 quadrupole coil, two blocks in each layer are separated by a wedge.
- Rutherford cable with a trapezoidal angle of 1.9 degrees is twisted by 10 Nb-Ti strands.
- The inner and outer radii of the iron are 29 mm and 52 mm.
- High order field harmonics are within $1 \times 10^4$.

**Racetrack coil structure**
- Two-layer racetrack quadrupole coil.
- Rectangular Rutherford cable with a width of 2.5 mm and a height of 0.85 mm is twisted by 10 Nb-Ti strands.
- The inner edge of iron is a regular octagon, and each edge is 29 mm from the center of aperture.
- High order field harmonics are within $1 \times 10^4$.

**CCT coil structure**
- Complete the conversion of coordinate points from local coordinates to global coordinates. Use the 20-node pattern to splice the CCT coil.
- The conductor is consist of 12 Nb-Ti strands, the cross-sectional size is 1 mm $\times$ 3 mm.
- The inner and outer radii of the iron are 30 mm and 52 mm.

**RESULT**

- Cos20 quadrupole coil is used to design the double-aperture superconducting quadrupole magnet Q1a.
- Using FeCoV material, the outer radius of iron is reduced to 40.5 mm. The dipole field at the center of each aperture is 17.316 Tm. The filed harmonics at reference radius of each aperture are less than $2 \times 10^4$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>1965 A</td>
</tr>
<tr>
<td>Gradient</td>
<td>141.8102 T/m</td>
</tr>
<tr>
<td>Weight</td>
<td>74.78 Kg</td>
</tr>
<tr>
<td>Dipole field at center of each aperture</td>
<td>17.316 Tm</td>
</tr>
<tr>
<td>$b_1$ (unit 10^-3)</td>
<td>-1.04397</td>
</tr>
<tr>
<td>$b_2$ (unit 10^-5)</td>
<td>-0.01436</td>
</tr>
<tr>
<td>$b_3$ (unit 10^-5)</td>
<td>0.48833</td>
</tr>
</tbody>
</table>

**Design and optimization of double-aperture Q1a based on cos20 coil**

- The double-aperture magnet Q1a is designed according to the same polarity, magnetic field gradient and field quality requirements in each aperture.
- In the pure coil model, the dipole field at the center of the aperture reaches 1000 Gs. So far, no pure coil model that meets the physical requirements has been found.
- Complete the double-aperture superconducting quadrupole magnet Q1a.
- Improve the magnetic saturation strength by changing the iron material. Reduce the outer radius of iron.

<table>
<thead>
<tr>
<th>Option</th>
<th>Main features</th>
<th>Performance</th>
<th>Weight (kg)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 layers coil, iron-free</td>
<td>Large dipole field, 20% larger current</td>
<td>36</td>
<td>Smallest weight, field crosstalk not solved</td>
</tr>
<tr>
<td>2</td>
<td>2 layers coil, DT4 iron</td>
<td>Meet all requirements (Dipole &lt;30Gn)</td>
<td>95.41</td>
<td>Largest weight</td>
</tr>
<tr>
<td>3</td>
<td>2 layers coil, FeCoV iron</td>
<td>Meet all requirements (Dipole &lt;30Gn)</td>
<td>74.78</td>
<td>Manufacture cost increases slightly</td>
</tr>
<tr>
<td>4</td>
<td>1 layer coil, FeCoV iron</td>
<td>Meet all requirements (Dipole &lt;30Gn)</td>
<td>60.2</td>
<td>Double current carrying capacity, 5 years later</td>
</tr>
</tbody>
</table>

**CONCLUSION**

- Cos20 quadrupole coil: high excitation efficiency, complex coil shape, complex supporting structure.
- Racetrack quadrupole coil: low excitation efficiency, simple coil shape, friendly to high-temperature superconductors.
- CCT quadrupole coil: simple support structure, low cooling efficiency.
- Complete the double-aperture superconducting quadrupole magnet Q1a, meet the requirements of high-order field harmonics, dipole field and the weight.

**REFERENCE**

1. Guo Jie, CEPC and SpC Status—From the completion of CDR towards TDR.
2. P. Ferracin, G. Ambrosio, et al., Magnet Design of the 150 mm Aperture Low-beta Quadrupoles for the High Luminosity LHC.