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Superconducting quadrupole magnets in the interaction region of CEPC and BEPCII-U

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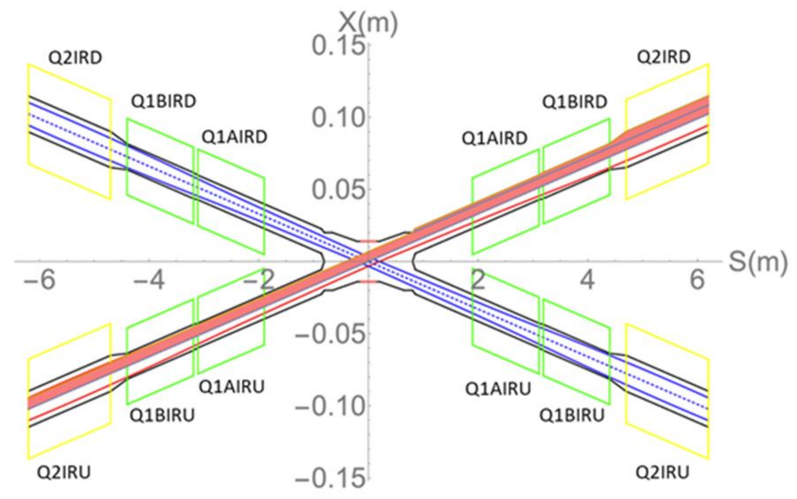
Abstract

This poster presentation includes research progress on superconducting quadrupole magnets in the interaction region for two current Chinese electron positron collider projects. One section describes the study on CCT ironless dual aperture superconducting quadrupole magnets in the interaction region being designed for the CEPC. And the other section describes the combined superconducting magnets in the interaction region being manufactured for the BEPCII Upgrade project.

Introduction

The accelerator of CEPC is now in the engineering design phase, which places more stringent requirements on the design of the superconducting quadrupole magnets in the interaction region. The need to reduce both the weight of the superconducting magnets and the deformation of the cantilevered support has led to the proposal of an ironless magnet solution. As the dual aperture magnets are not shielded by iron yokes, crosstalk will affect the magnetic field quality. For this reason, we propose the ironless dual aperture superconducting quadrupole magnet without correction coils.



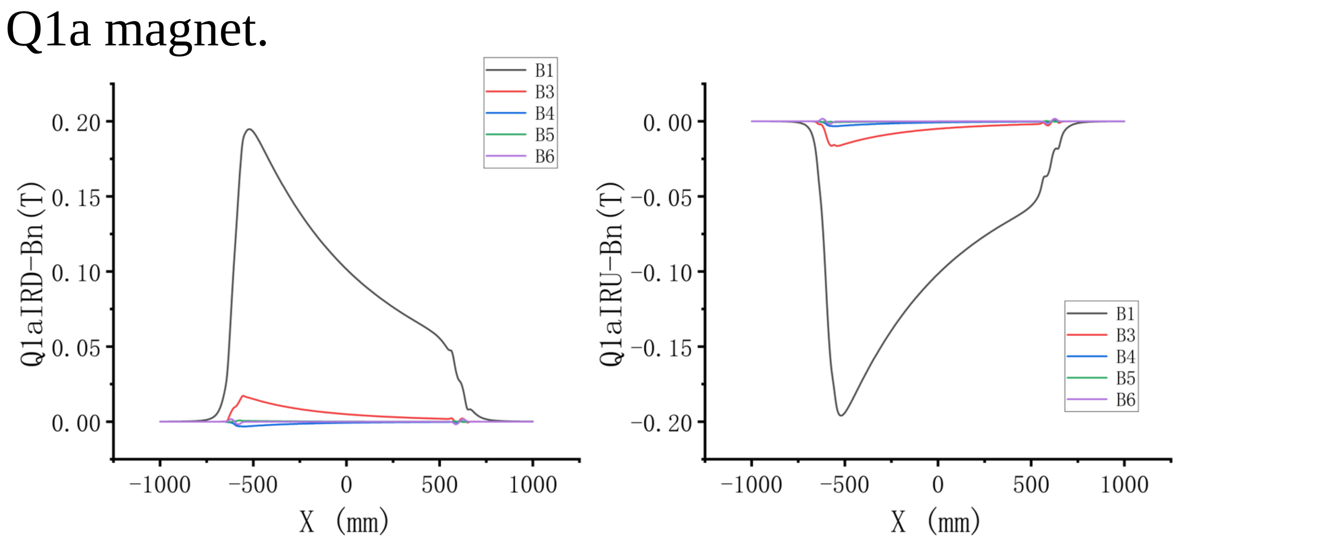
Layout of SCQ magnets in the interaction region.

Purpose

The dual-aperture superconducting quadrupole magnet Q1a, with the interaction region closest to the interaction point and the smallest distance between the two apertures in the Higgs mode, is taken as an example. The magnetic field quality problems caused by crosstalk and edge effects between the two apertures of the magnet are solved to meet the EDR requirements for the Q1a magnet.

Item	Value	Unit
Position from the IP	1900	mm
Magnetic field gradient	142.3	T/m
Reference radius	7.46	mm
Magnetic length	1210	mm
Distance between two aperture beam lines at tip	62.71	mm
Integrated field harmonics	≤3×10-4	-
Dipole field in aperture	≤300	G

Requirements of Q1a magnet.



Uncorrected CCT Q1a magnet multipole components.

Method

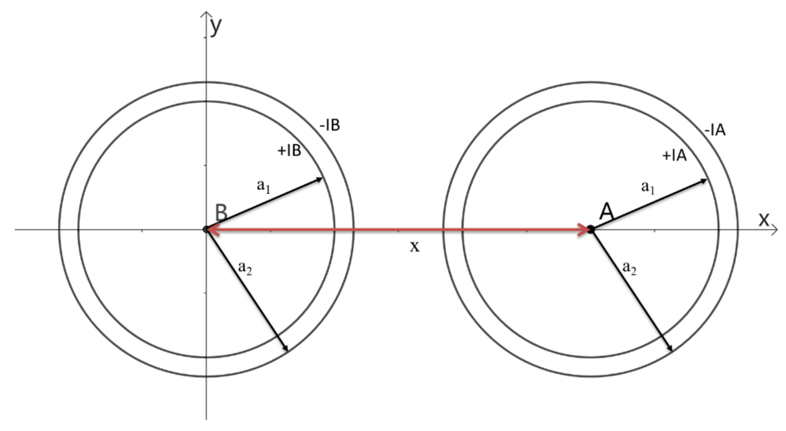
The CCT coil path can be expressed by the equation, and the surface current density is used to derive the corresponding current density distribution of the coil and the magnetic field it generates. Therefore, by modifying the coil path equation, the current density distribution of the coil can be adjusted and new multipole magnetic fields can be added without the corrector coils.

Modified CCT coil path equation:

$$\vec{P}(\theta) = \begin{cases} R\cos\theta \\ R\sin\theta \\ \dfrac{R}{n\tan(\alpha)}\sin(n\theta) + \dfrac{w\theta}{2\pi} + z' \end{cases}, -\pi N \le \theta \le \pi N$$

$$z' = \sum_{n_1}\left(C_m \frac{R\sin(n_1\theta)}{n_1 \tan\alpha}\right) + \sum_{n_2}\left(D_m \frac{R\cos(n_2\theta)}{n_2 \tan\alpha}\right)$$

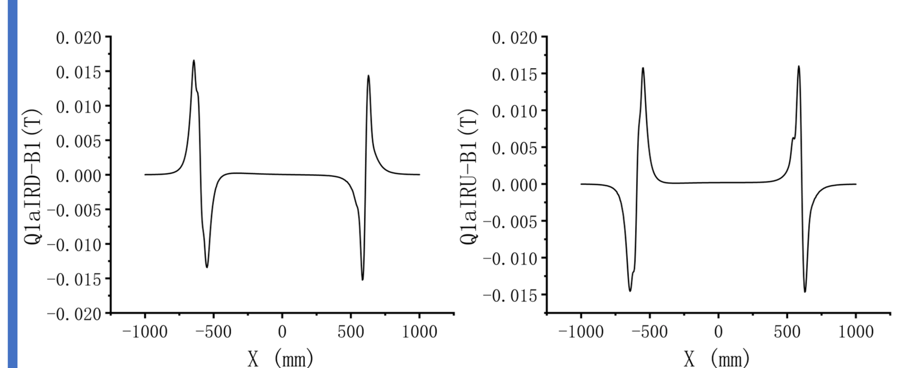
$$\begin{cases} C_A = (-1)^{n-1} C_{n+m-1}^{n-1} \dfrac{I_B}{I_A}\left(\dfrac{R}{x}\right)^{n+m} \\ C_B = (-1)^{2n+m-1} C_{n+m-1}^{n-1} \dfrac{I_B}{I_A}\left(\dfrac{R}{x}\right)^{n+m} \end{cases}$$



R: coil radius (a1,a2), w: turn advance, θ: azimuthal angle around the cylinder, α: inclination angle, n: multipole order, x: distance between the centres of the apertures, +IA /+IB: inner current of A/B, -IA /-IB: outer current of A/B.

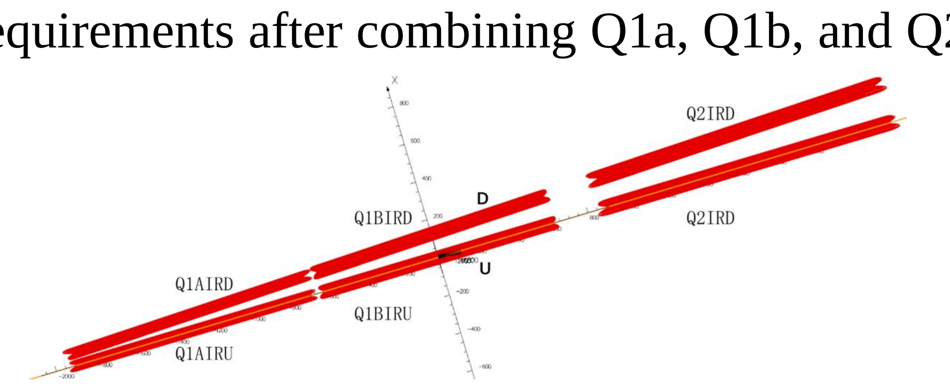
An additional 2n-pole magnetic field is generated to correct the interference field generated by another aperture 2m-pole magnetic field.

Result



Corrected CCT Q1a magnet B1 components.

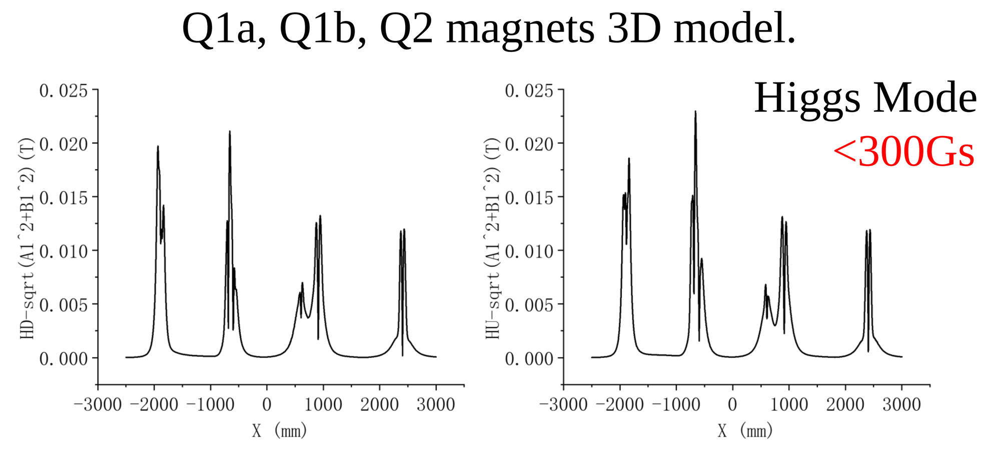
The critical aspect of the magnet combination analysis is to determine whether the magnitude of the dipole field amplitude meets the physical requirements after combining Q1a, Q1b, and Q2.



Q1a, Q1b, Q2 magnets 3D model.

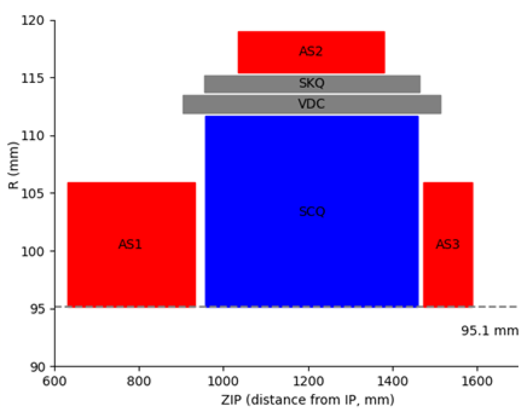
n	Q1AIRD	Q1AIRU	Q1BIRD	Q1BIRU	Q2IRD	Q2IRU
	B_n/B_2 (Higgs Mode) ≤3×10-4					
	Rref=7.46mm		Rref=9.085mm		Rref=12.24mm	
2	1	1	1	1	1	1
3	8.54E-05	-1.00E-04	6.13E-06	-2.20E-05	-1.20E-04	9.89E-05
4	-7.90E-06	-2.70E-05	-5.70E-07	-4.60E-06	1.47E-05	1.34E-05
5	-1.40E-04	1.39E-04	-2.70E-05	2.64E-05	-9.80E-06	9.98E-06
6	1.56E-05	1.57E-05	-3.40E-07	-3.10E-07	-3.00E-06	-3E-06
7	-2.90E-06	3.11E-06	-2.70E-07	2.80E-07	-2.30E-07	5.44E-08
8	2.76E-07	6.23E-07	2.34E-08	2.40E-08	-4.00E-08	-7.8E-08
9	-9.00E-10	-7.30E-08	5.86E-08	8.81E-09	1.17E-07	3.75E-08
10	2.94E-08	2.08E-07	-2.10E-08	5.11E-08	-5.70E-08	1.88E-07

Harmonics of Q1a, Q1b, Q2.



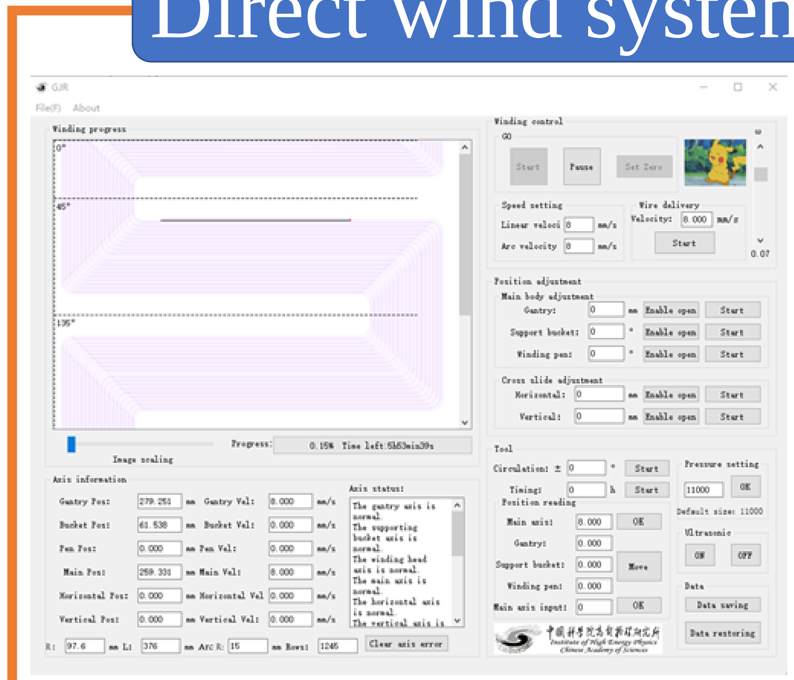
Amplitude of Q1a, Q1b, Q2 dipole field.

BEPCII-U

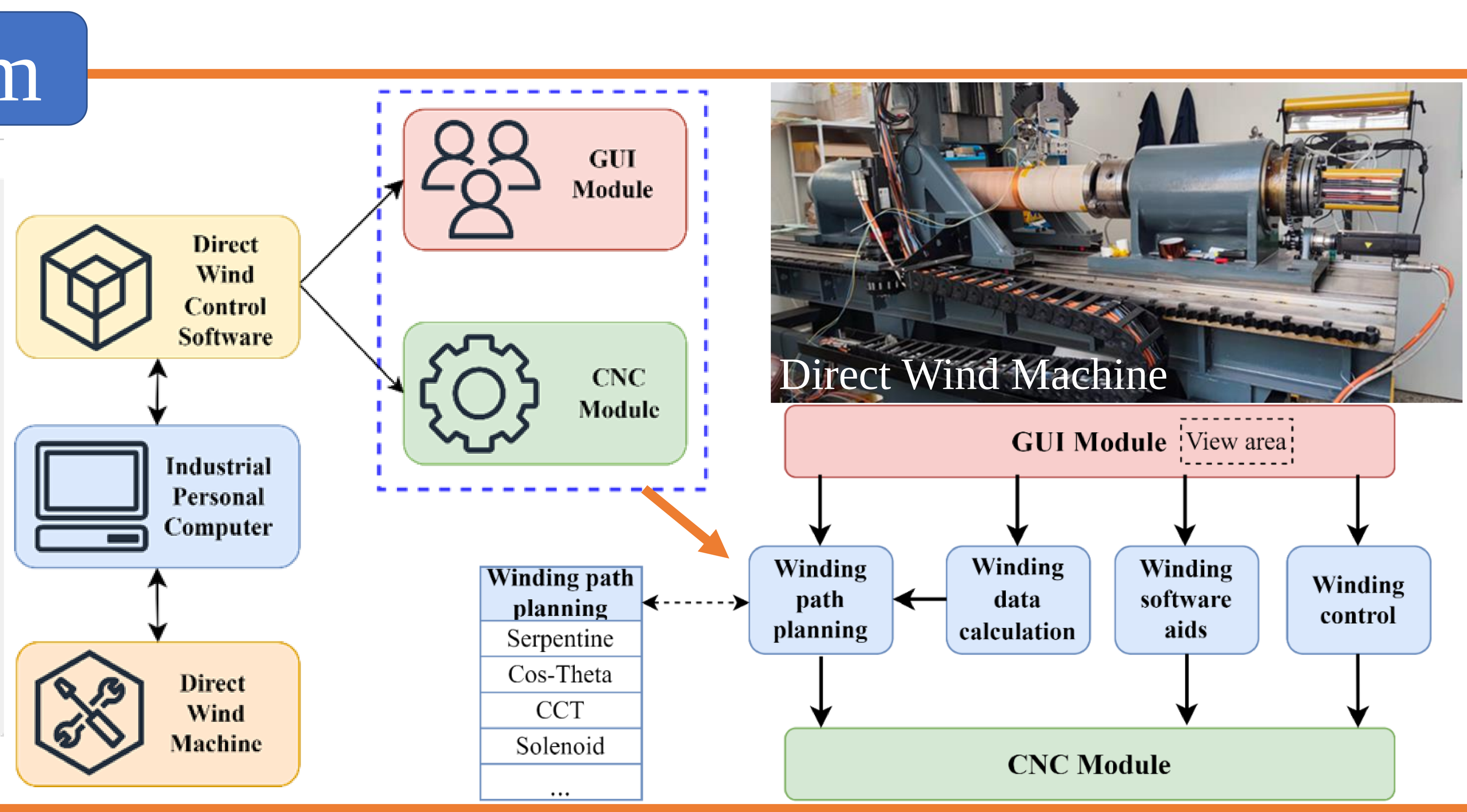


The BEPCII-U aims to extend the beam energy to 2.8 GeV and to enhance the luminosity at the optimized energy of 2.35 GeV from 3.5×10^{32} $cm^{-2}s^{-1}$ to 3.5×10^{32} $cm^{-2}s^{-1}$. It requires the development of combined superconducting magnets with higher magnetic field gradients for the interaction region. The challenge lies in producing combined superconducting magnets that meet high magnetic field precision requirements, it is essential to ensure that the coil winding process is both stable and precise. Using the developed direct winding system, the combined superconducting magnets were manufactured and passed the process tests.

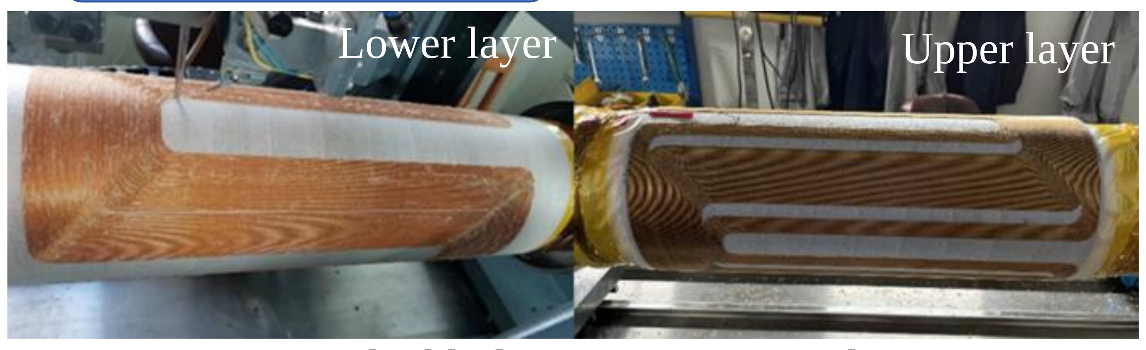
Direct wind system



GUI of direct wind system.



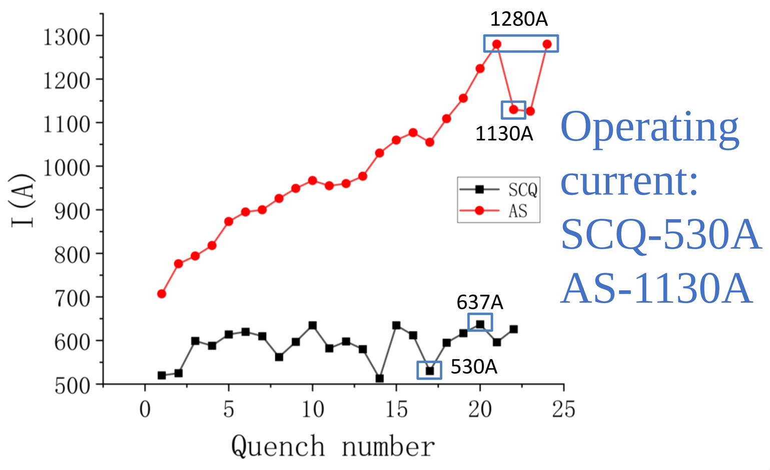
Manufacture



SCQ double-layer serpentine coils.

AS1 solenoid coil winding.

Finished superconducting magnet



Operating current:
SCQ-530A
AS-1130A

Quench training plot.

n	530A	600A	630A
	B_n/B_2 (SCQ)		
2	1	1	1
3	1.15E-04	1.17E-04	1.15E-04
4	1.12E-04	1.06E-04	1.03E-04
5	3.38E-05	3.65E-05	3.45E-05
6	1.15E-04	1.24E-04	1.30E-04
7	2.62E-05	1.47E-05	8.93E-06
8	2.33E-05	2.58E-05	2.31E-05
9	2.01E-05	3.30E-05	2.69E-05
10	5.88E-05	6.08E-05	7.49E-05

$B_n/B_2 \le 3\times10^{-4}$

SCQ magnet harmonics.