MECHANICAL DESIGN AND MANUFACTURE OF ELECTROMAGNETS IN HEPS STORAGE RING

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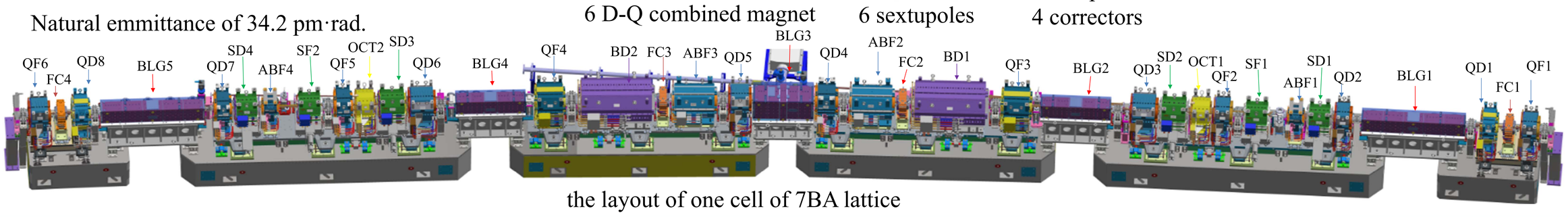
Abstract

The HEPS storage ring comprises 48 7BA (seven-bend achromat) cells. There are 37 independent magnets in every cell, of which 5 dipoles are permanent magnets and the rest of magnets are all electromagnets including quad-rupoles, D-Q(dipole-quadrupole) combined magnets, sextupoles, octupoles and corrector magnets. These electromagnets with small aperture and high magnetic field gradient should achieve high machining and assembly precision. In October 2023, all storage ring electroma gnets manufacturing have been completed. This poster mainly introduces the mechanical design, processing and assembly, and the manufacturing issues in the machinin g period.

HEPS storage ring: 48 7BA cells (24 super-periods)
Circumference 1360.4 m
Natural emmittance of 34.2 pm·rad.

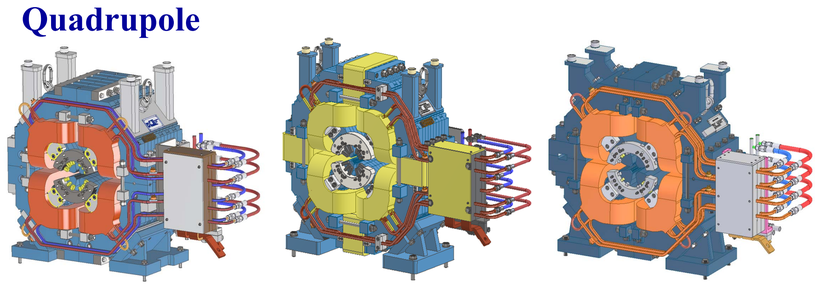
37 independent magnets
5 dipole
6 D-Q combined magnet
14 quadrupoles
6 sextupoles
2 octupoles
4 correctors



the layout of one cell of 7BA lattice

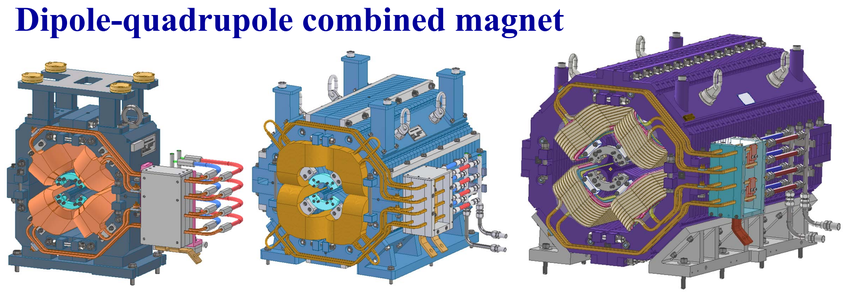
DESIGN AND ASSEMBLY

Quadrupole



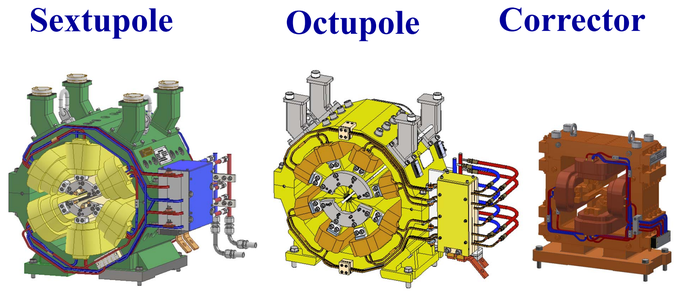
Type I Type I+ Type II

Dipole-quadrupole combined magnet



ABF1/4 ABF2/3 BD1/2

Sextupole **Octupole** **Corrector**



SD1/4 OCT1/2 FC1/2/3/4

Design &manufacture time:

- 2019.9-2023.10 ~4 years

Characteristics:

- Small aperture, high magnetic gradient, high precision, compact layout

Maching tolerance

- Laminated magnets: pole space ≤±0.03mm magnet lenth ≤±0.25mm
- Machining magnets: pole space ≤±0.02mm magnet lenth ≤±0.05mm

Magnet type	Section size /mm×mm	Yoke length /mm	Processing method	Aperture/ mm	Pole space/mm	Others
Type I	510×510	180(QD2),201(QF2,QF1/6odd), 245(QF1/6even),260(QD5), 327(QD3/6)	Stacking laminations	26	11	
Type I+	540×540	180(QD1/8odd),192(QD1/8even), 374(QF3/4)	Stacking laminations	26	11	Correction coil
Type II	510×510	180(QD7),201(QF5), 260(QD4)	Milling&EDM	26	11	Light channel
ABF1/4	336×336	180	Milling&EDM	30	11	
ABF2/3	480×480	580	Stacking laminations	30	11	Light channel
BD1/2	640×640	1040	Stacking laminations	45	9	
SD1/4	410×414	304	Milling	32	11.6	Correction coil
SF1/2	400×402	318	Milling&EDM	26.6	8	Light channel
SD2/3	450×464	350	Milling&EDM	26.6	8	Correction coil
OCT1/2	500×500	254	Milling&EDM	30	7.2	Correction coil
FC1/2/ 3/4	300×300	98.7	Stacking laminations		31	

QUALITY CONTROL MEASURES

Material

Laminations:mechanical blending&magnetic blending.
DT4 plates: a magnet type=same furnace;magnetic excitation test&annealing

Pole accuracy

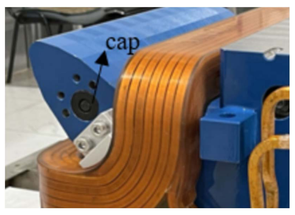
Laminations:punching &stacking precision ;
pole profile toleranc&yoke mating surface sraightn:≤0.01mm;
monitor positioning accuracy of the stacking mold.
Machining : milling&EDM tolerance≤ 0.02mm;one-time clamping.

Repeatability Accuracy

Reasonably arrange the cylindrical pins; use the pole clamps to fix the pole; control the bolt torque(60-80N·m) and bolting sequence(diagonally).

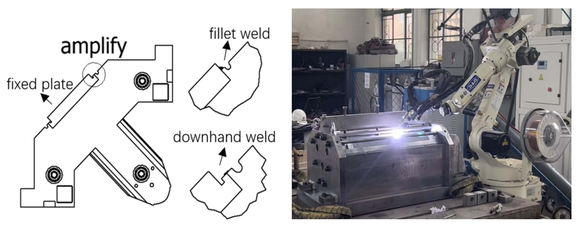
MAGNET DESIGN AND MANUFACTURING ISSUES

Filling Magnetic Material



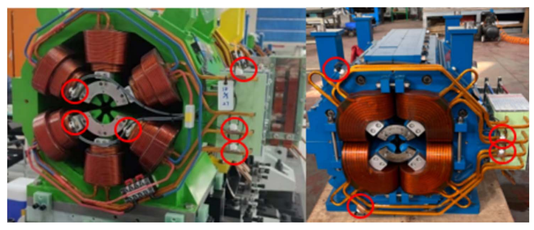
Add magnetic material to improve working current.

Optimize Welding Process



Downhand welding & robot welding to reduce distortion.

Optimize temperature switch

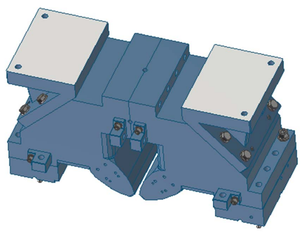


Switch distribution close to the pole: sextupole(36±3°C);quadrupole(43±3°C)

Dowel installation

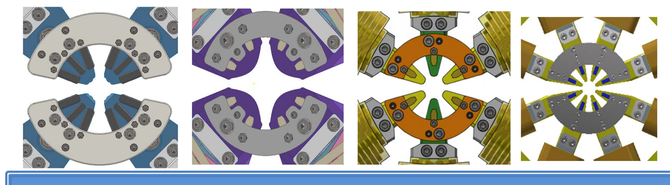
pre-installed dowel; remove upper half yoke; install correction coils.

Split baseplates



Confirm mounting hole positions when milling the bottom surface.

Magic finger: A fast and effective method of magnetic field harmonic compensation, a remedial measure.



Fixed by pole clamp, adjusted in the magic finger groove.

- The qualified rate of lamination magnets is high. Most don 't need a magic finger to qualify.
- Some machining magnets need to use magic finger to qualified:(eg BD1/2 ~16%, QD7 ~48%,QF5 ~64%).
  Reason:saturation of the magnetic properties of yoke. The number of magic fingers used per magnet is about 1-3.

CONCLUSION

Thanks to the efforts of magnet physicts, mechanical engineers and suppliers, HEPS magnet manufacturing is generally efficient and successful.All the electromagnets manufacturing of HEPS storage ring have been completed. Magnetic measurement and installation are being carried out. Some experiences and lessons have been obtain ed in mechanical design and processing.