R&D of CEPC Booster Magnets

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Main Specifications of CEPCB dipole magnets

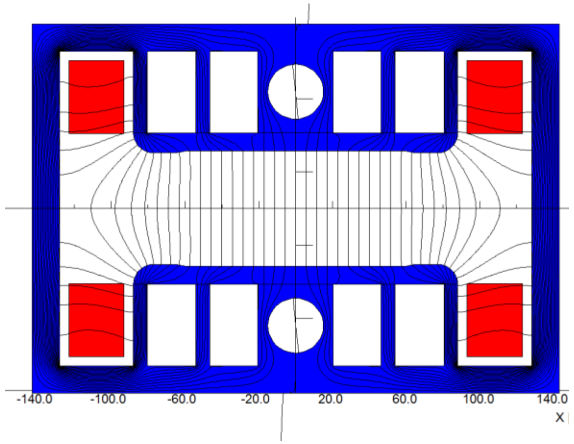
	BST-63B
Quantity	16320
Minimum field (Gs)	28
Maximum field (Gs)	338
Gap (mm)	63
Magnetic Length (mm)	4700
Good field region (mm)	55
Field uniformity	0.1%
Field reproducibility	0.05%

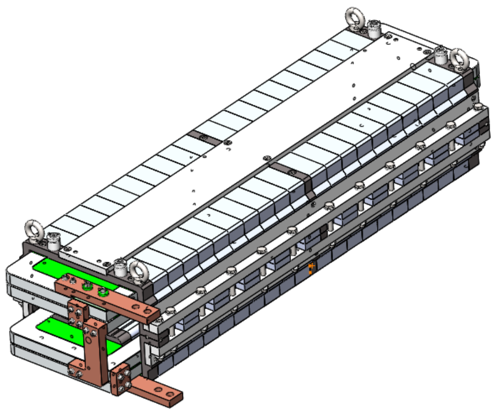
Two kinds of the subscale prototype magnet with and without iron cores have been designed and developed. The field quality of the magnet without iron cores reaches the specifications.

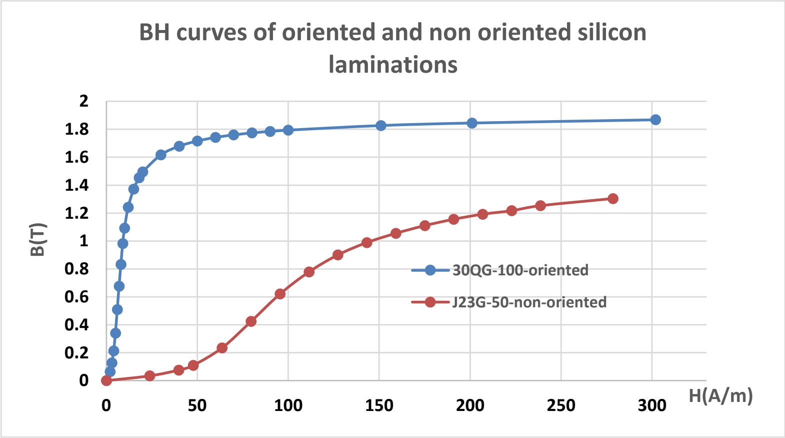
R & D of the dipole magnet with iron cores

1) Design of the dipole magnet with iron cores

- To increase field in the cores and decrease weight of the cores, the technology of core dilution is adopted.
- To reduce the influence of the remnant field on the low field precision, the grain-oriented silicon steel laminations are used to stack the magnet cores due to their low coercive and remnant field.



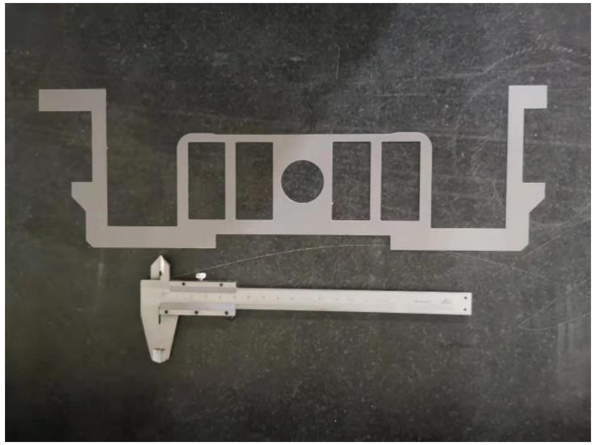


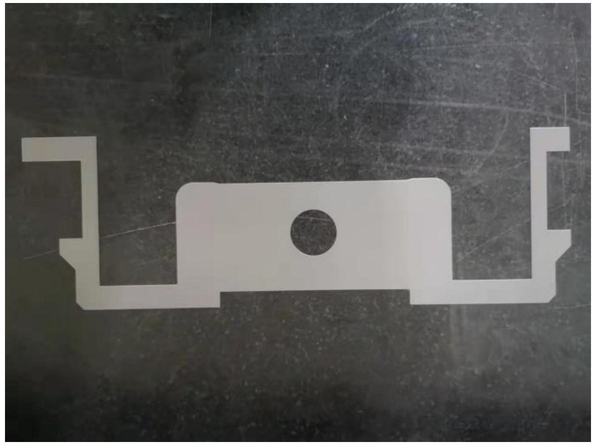


R & D of the dipole magnet with iron cores

2) Fabrication of the subscale prototype dipole magnet with iron cores

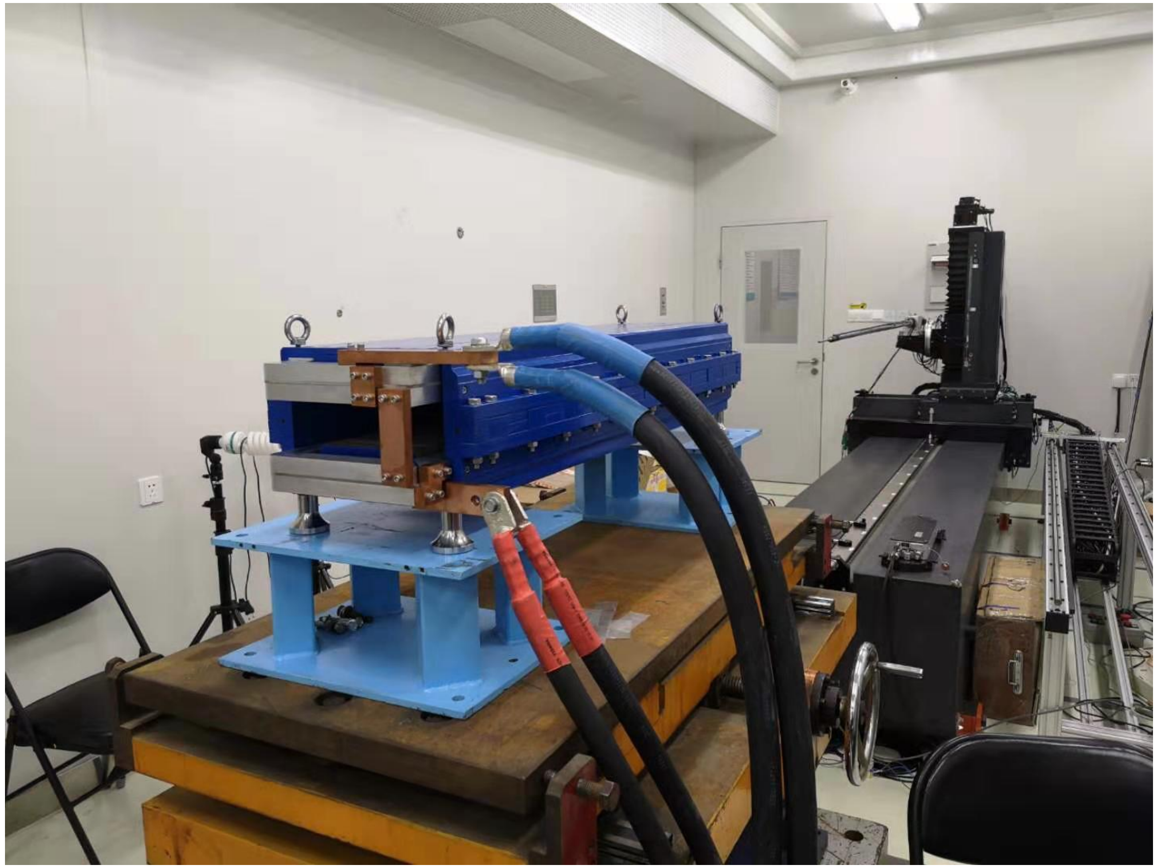
- The magnet has the upper and lower cores, which are stacked by the grain-oriented silicon steel and aluminum laminations with the thickness ratio of 1:1.
- To investigate the influence of the holes in the pole areas, two kinds of laminations with and without holes are produced. So each half of the cores is stacked by the laminations with the holes and half without holes.





R & D of the dipole magnet with iron cores

3) Test of the subscale prototype dipole magnet with iron cores

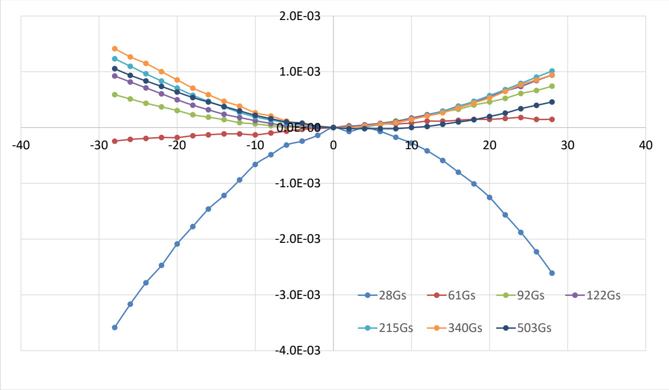


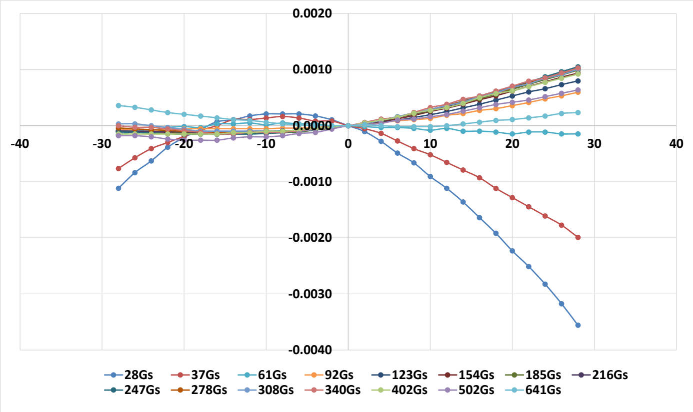
The dipole magnet with iron core was tested in the lab.

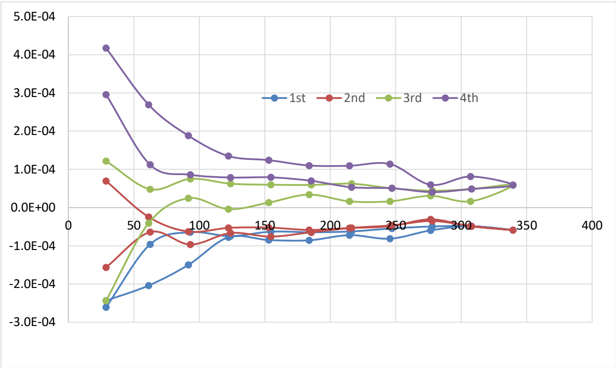
R & D of the dipole magnet with iron cores

The measurement results show,

- ✓ The field uniformity in GFR is about 0.3% at low field level of 28Gs and 0.1% at high field level, which can not meet the requirements.
- ✓ The magnet is excited for 4 times from 28Gs to 338Gs then back to 28Gs, the field reproducibility at all level is better than the required value of 5E-4.

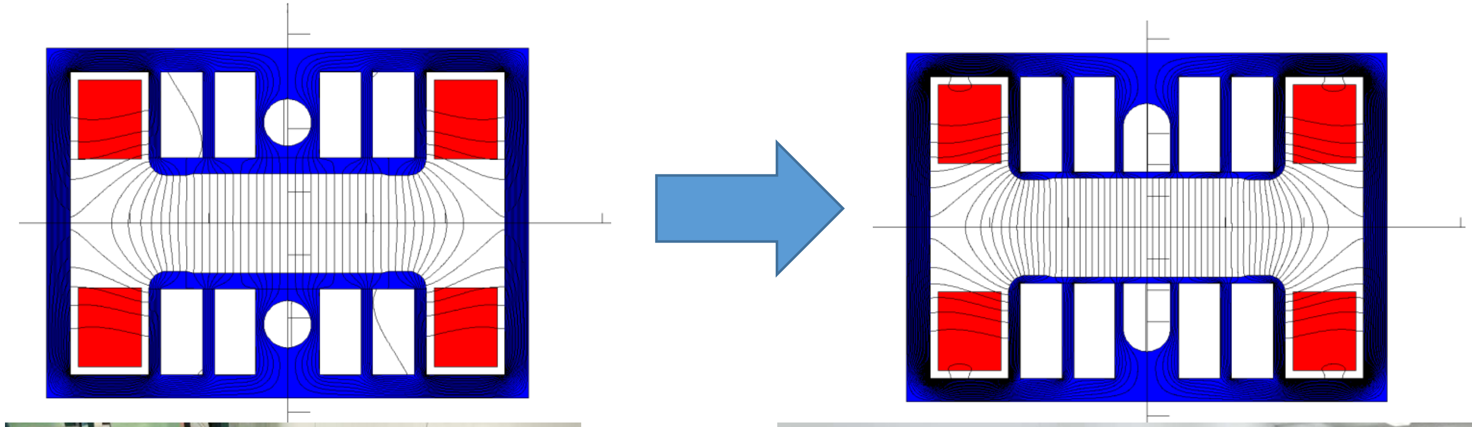


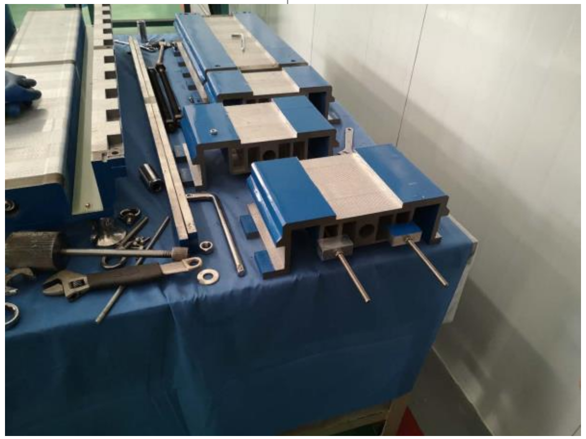




R & D of the dipole magnet with iron cores

In order to reduce the influence of the remnant field on the field quality, the subscale prototype dipole magnet was de-assembled and the holes of its laminations were reproduced. It was expected that the remnant field in the pole areas could be made uniform.

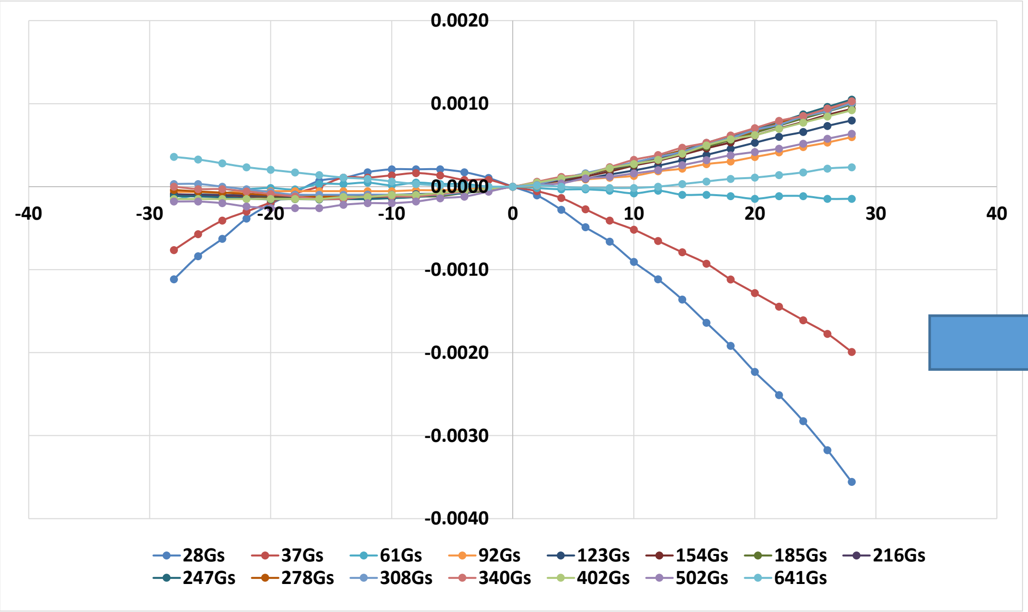


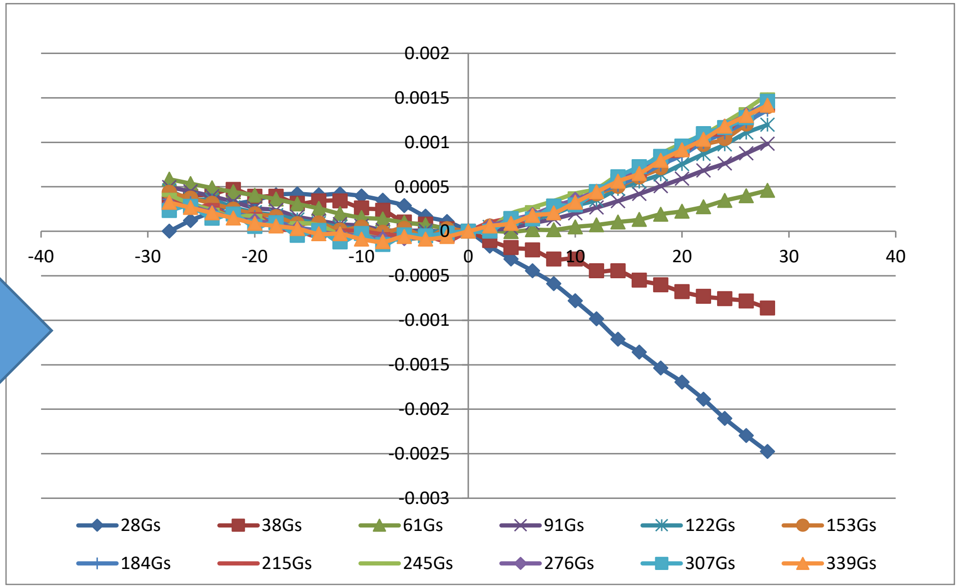


R & D of the dipole magnet with iron cores

The field measurement results show that the obvious modification of the magnet does not cause an obvious improvement on the low field quality.

The uniformity of low field of 28 Gs becomes a little better, from 0.35% to 0.25%, whereas the uniformity of high field level becomes a little worse, from 0.1% to 0.15%

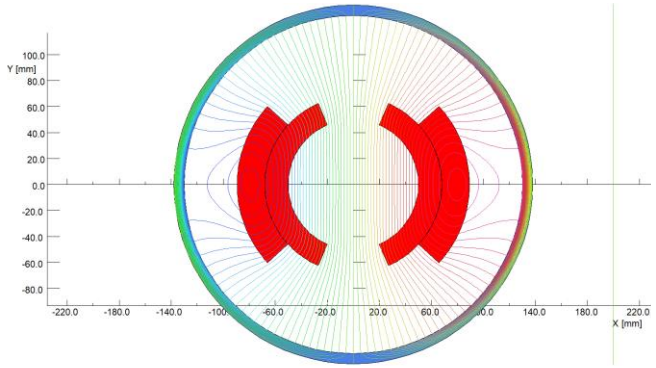


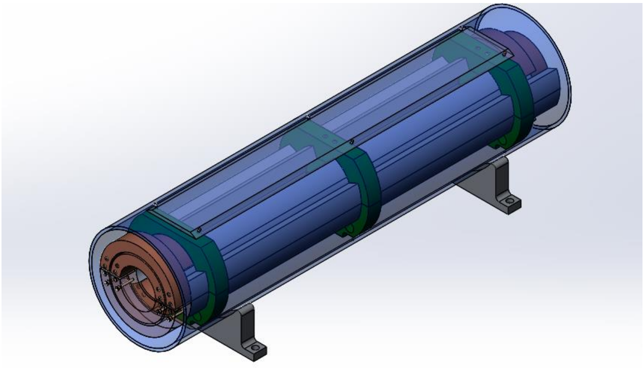


R & D of the dipole magnet without iron cores

1) Design of CT dipole magnet without iron core

- The Cosθ (CT) coil is a conventional measure for high field superconducting magnets, it is the first time for design of the high precision low field magnet.
- To reduce the production cost, the two CT coils are designed as simple as possible. In the structure, each coil has two layers and three turns, which are produced by aluminum bars with the same cross section areas.

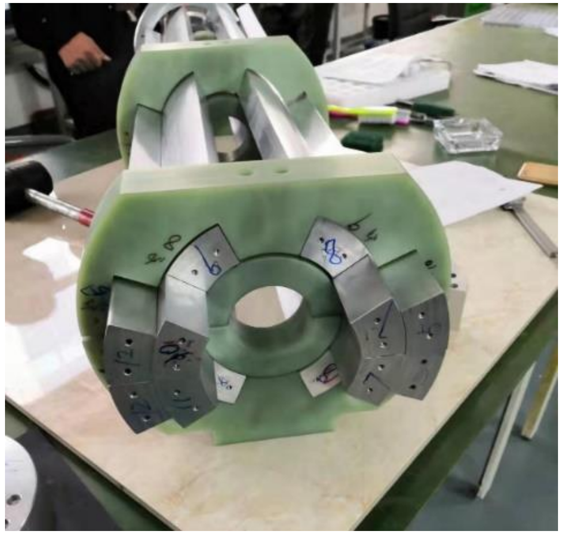
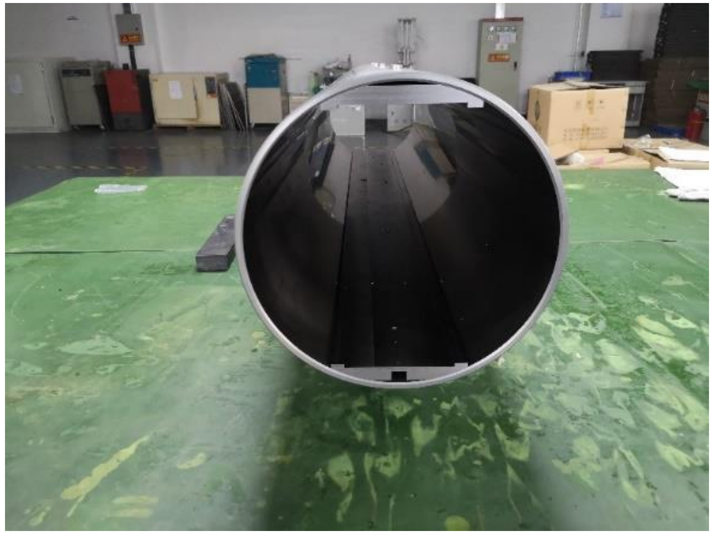




R & D of the dipole magnet without iron cores

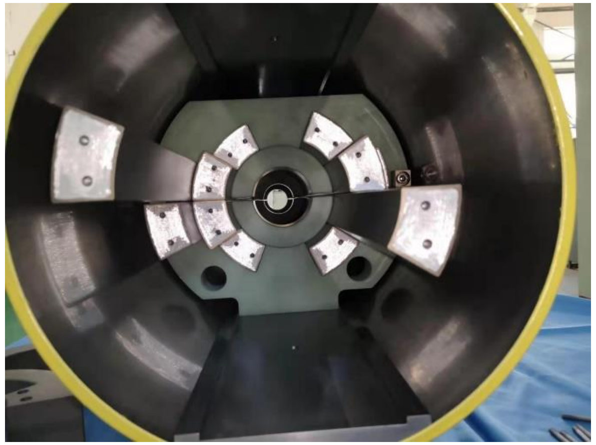
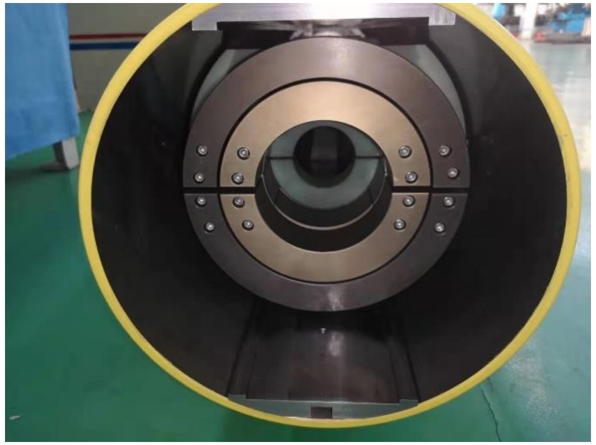
2) Fabrication of the subscale CT dipole magnet without iron core

- The inner and outer conductors of the CT coils are directly fabricated from two aluminum tubes with the right diameters.
- The shielding cylinder was made from a long iron tube with inner diameter of 300mm.

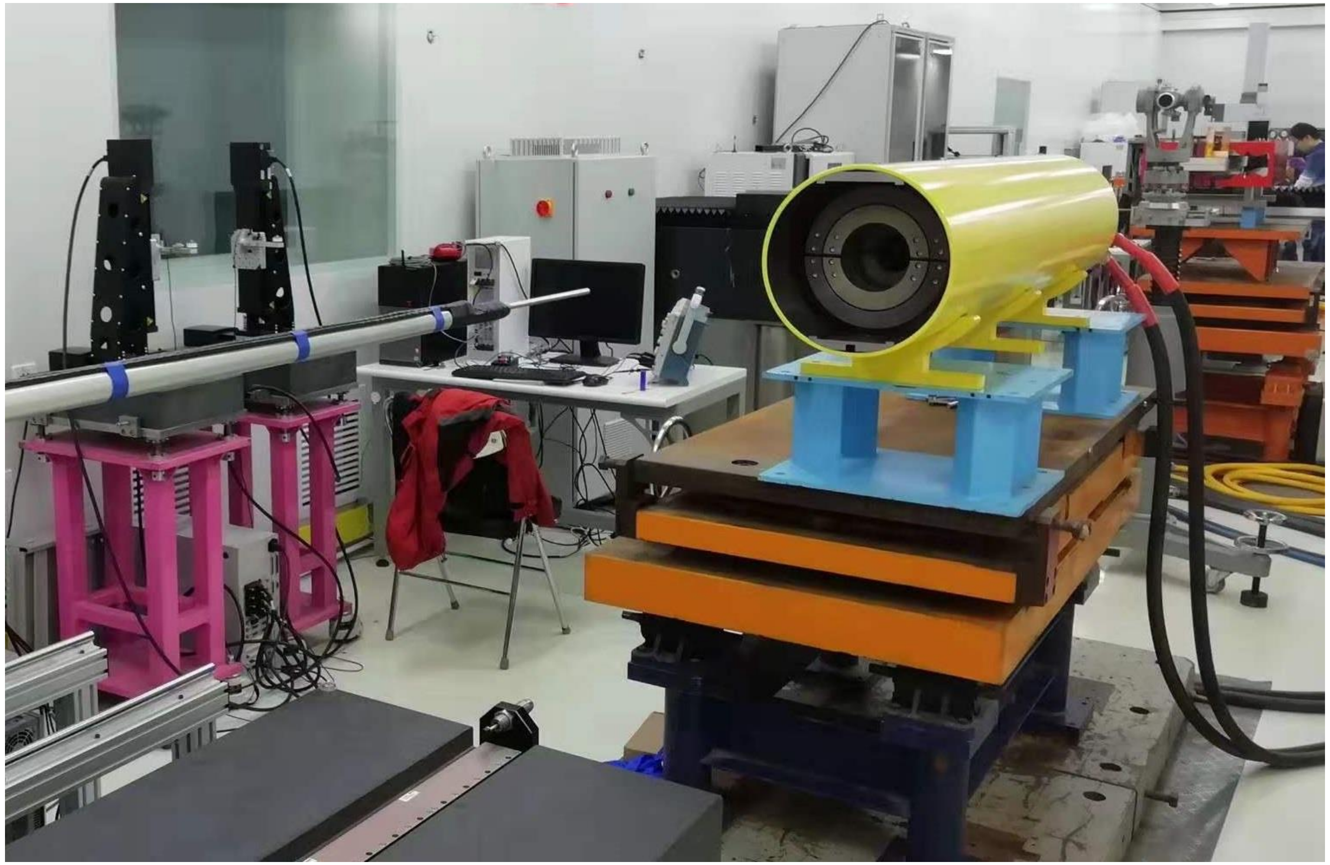
R & D of the dipole magnet without iron cores

- All the surfaces of the aluminum conductors were anodized for the insulation from turn to turn, the thickness of the anodized film is about 50 microns.
- The inner and outer conductors of the coils were connected by the by-pass circular conductors, the anodized film of the connected touch surfaces was gotten rid of before the conductors were connected.
- The final assembling errors of the CT coil dipole magnet were checked to be less than 50 microns.

R & D of the dipole magnet without iron cores

3) Test of the CT coil dipole magnet without iron core

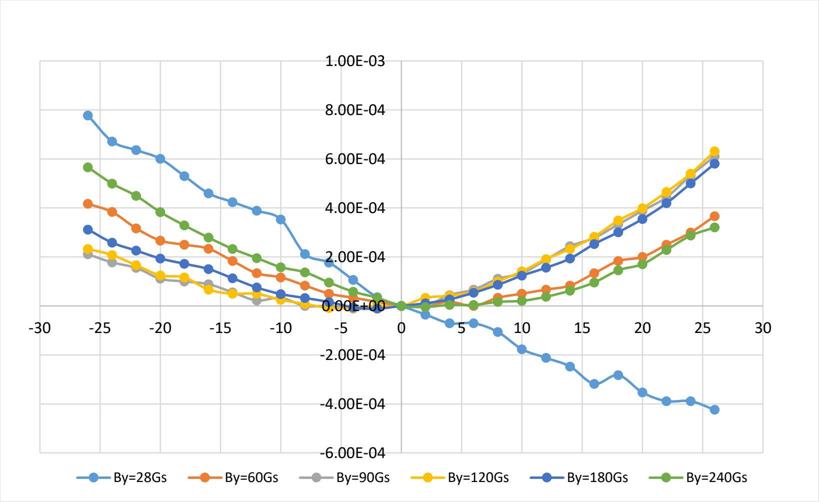


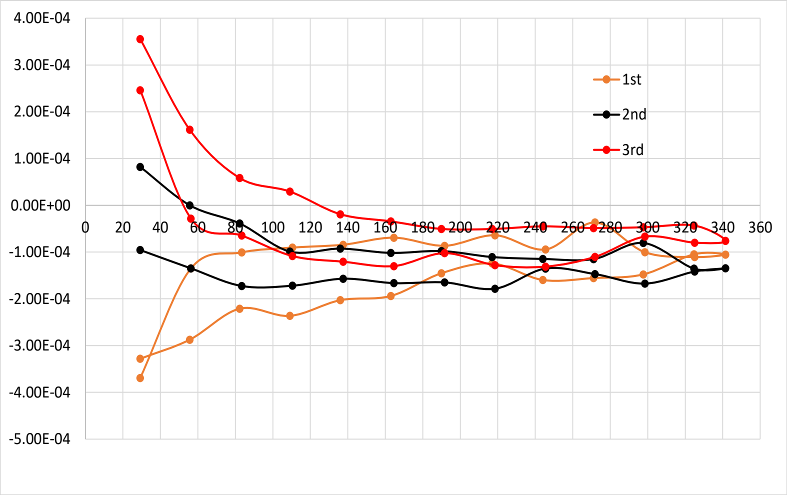
The CT coil dipole magnet was tested in the lab.

R & D of the dipole magnet without iron cores

The measurement results show,

- ✓ **The field precision at all level, especially at low field level of 28Gs, is better than the required value of 0.1.**
- ✓ **The magnet is excited for 3 times from 28Gs to 338Gs then back to 28Gs, the field reproducibility at all level is better than the required value of 5E-4.**

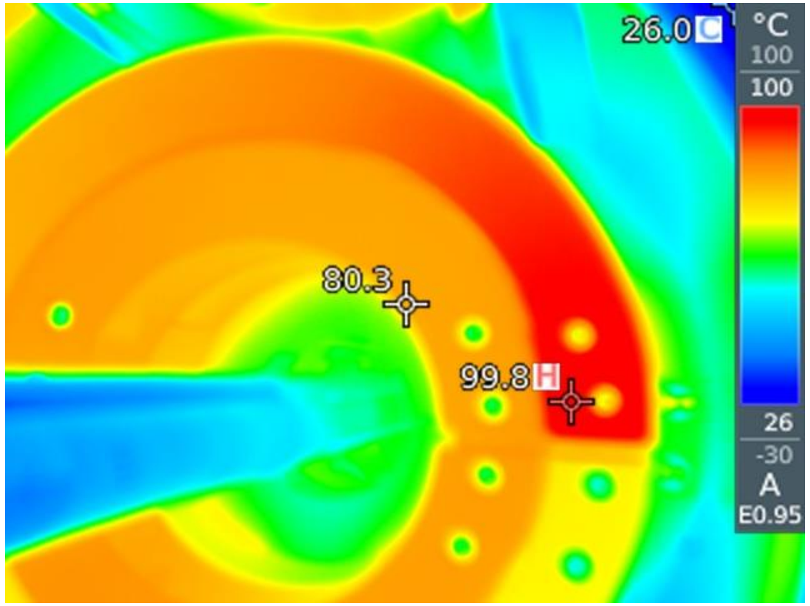




R & D of the dipole magnet without iron cores

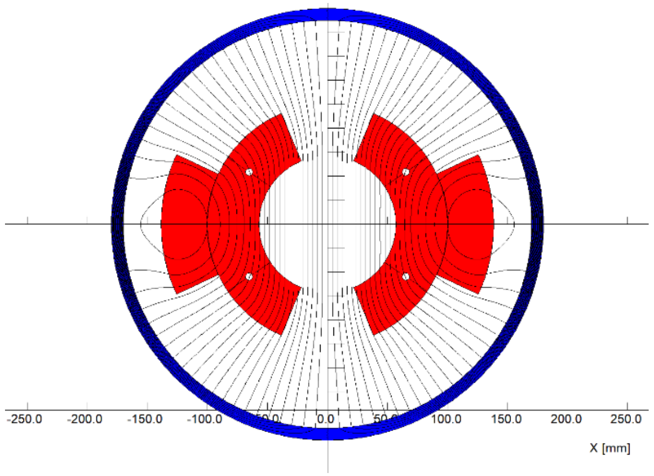
A serious problem is that the temperature of the coils increases to 80ºC-100ºC when the field increases to high level.

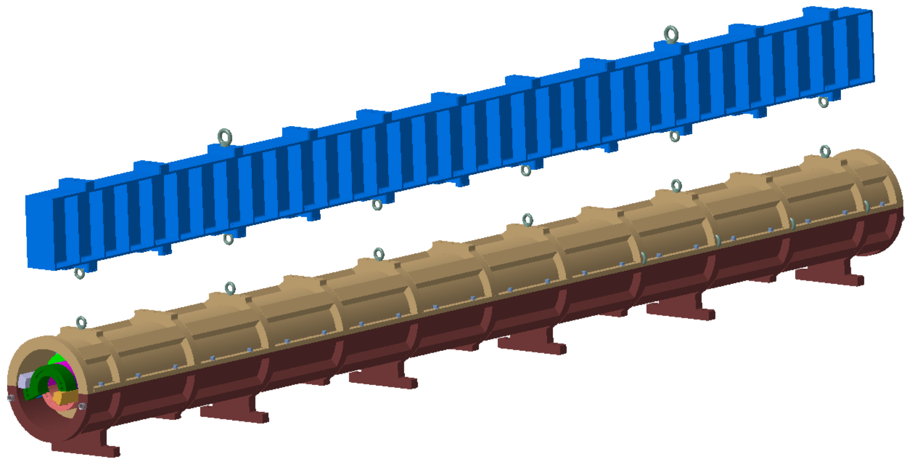
- ✓ The reason is that the aluminum alloy not the pure aluminum was selected as the material of the conductors due to its good mechanical properties.
- ✓ The resistivity of the aluminum alloy is 1.6 times larger than the pure aluminum, so the power loss of the coils increases by 1.6 times.
- ✓ In addition, the touch resistance of the contacted surfaces of the conductors is larger than the expected one.

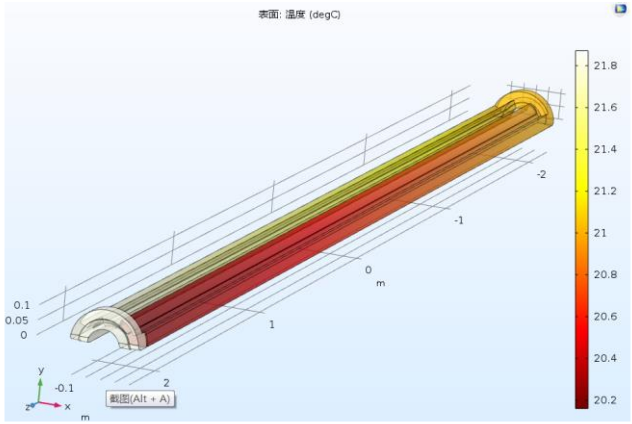


Design of the full-scale prototype CT coil dipole magnet

On the base of good results from the subscale CT dipole magnet, the mechanical design of a full scale prototype CT dipole magnet was finished. The production of the magnet will be begun in the coming month.



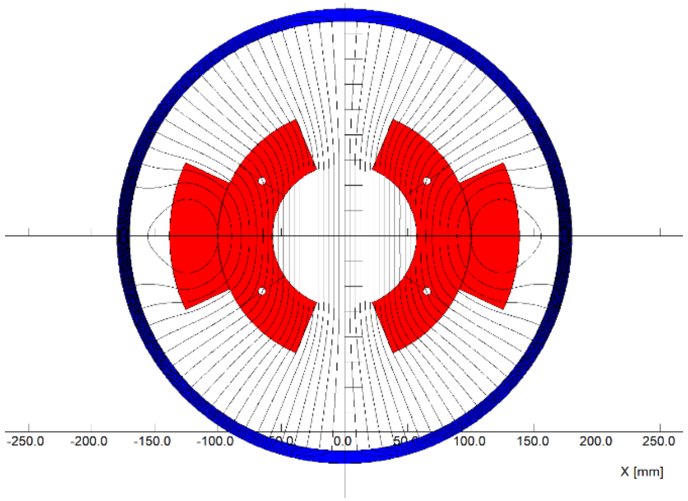


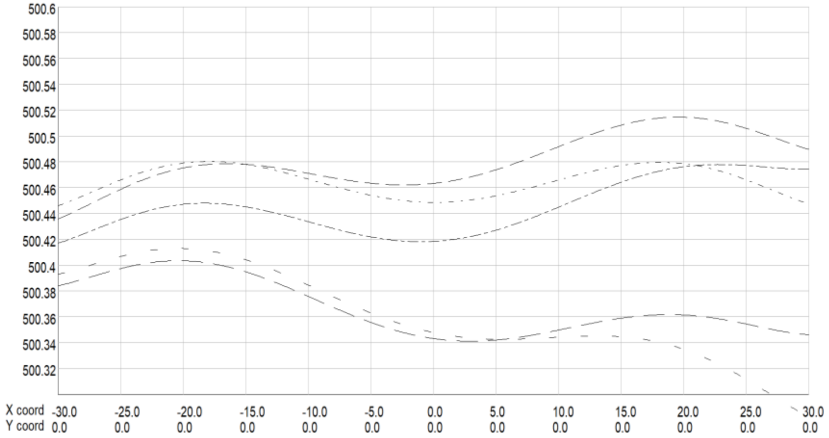


- ✓ The total length of the magnet including the shielding tube is 5.1m.
- ✓ The coil conductors will be made from pure aluminum, the cooling tubes will be inserted between the inner conductors to decrease temperature rise.
- ✓ The touch resistance of the contacted surfaces of the conductors will be reduced by coated silver films.

Design of the full-scale prototype CT coil dipole magnet

The size and position tolerance of the conductors are the key factors for the precision of the field.



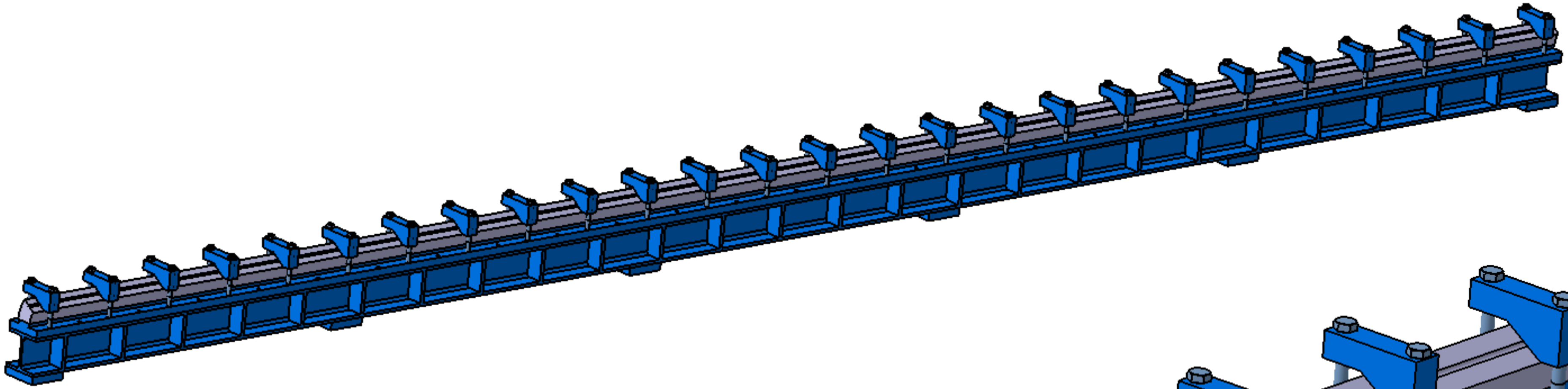


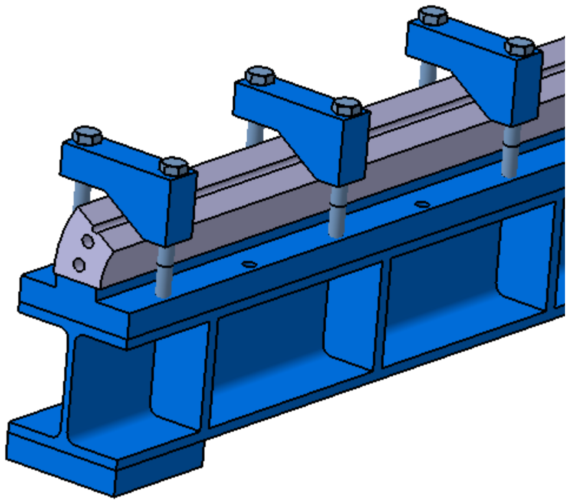
The field simulation shows,

- ✓ **The tolerance of size dimension for all conductors should be less than 0.05mm.**
- ✓ **The position tolerance of the conductors should be less than 0.1mm in 4.7m longitudinal direction.**

Design of the full-scale prototype CT coil dipole magnet

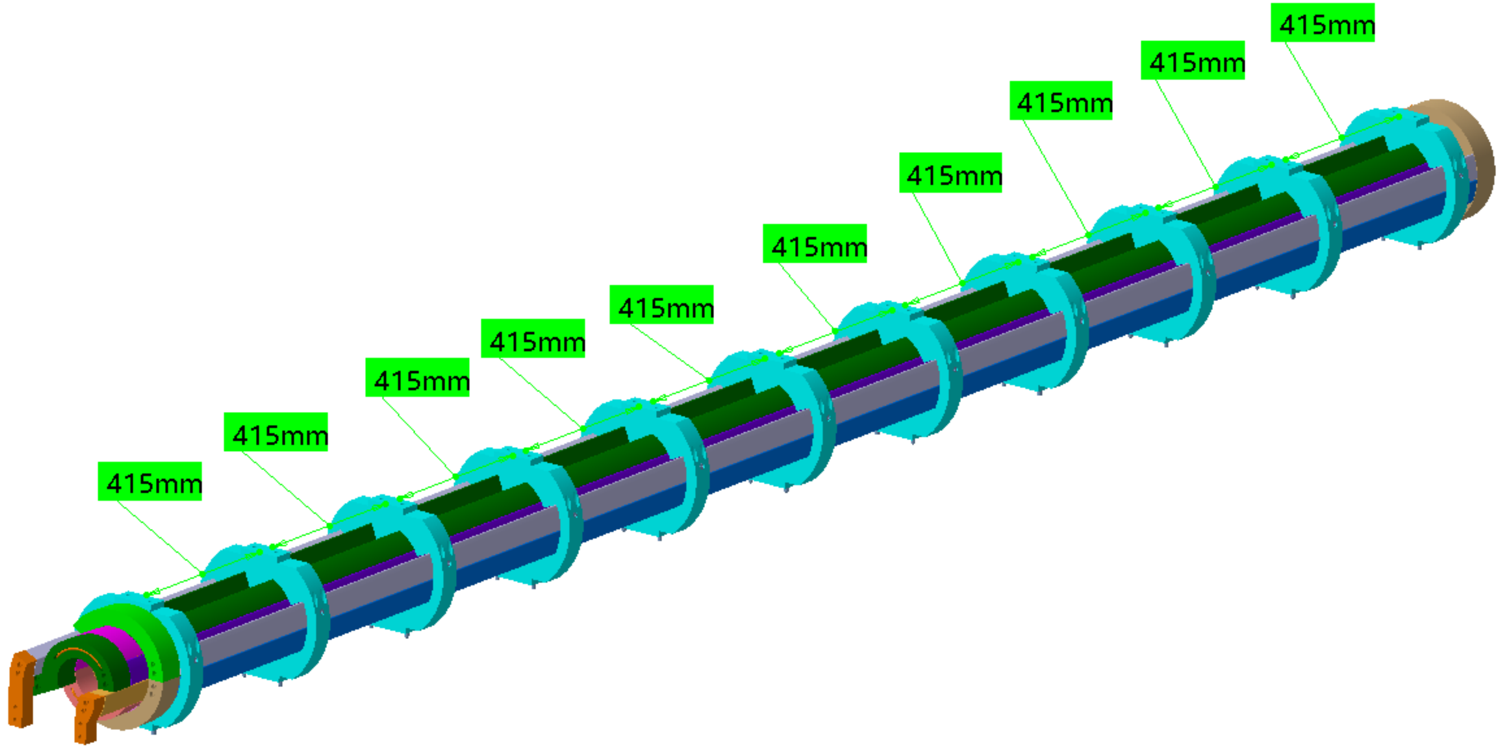
Each conductor is 4.7m long, which is directly fabricated from a long aluminum bar. In order to reduce the production cost. So the long conductor is considered to be divided into 3 parts for convenient fabrication and then assembled together.





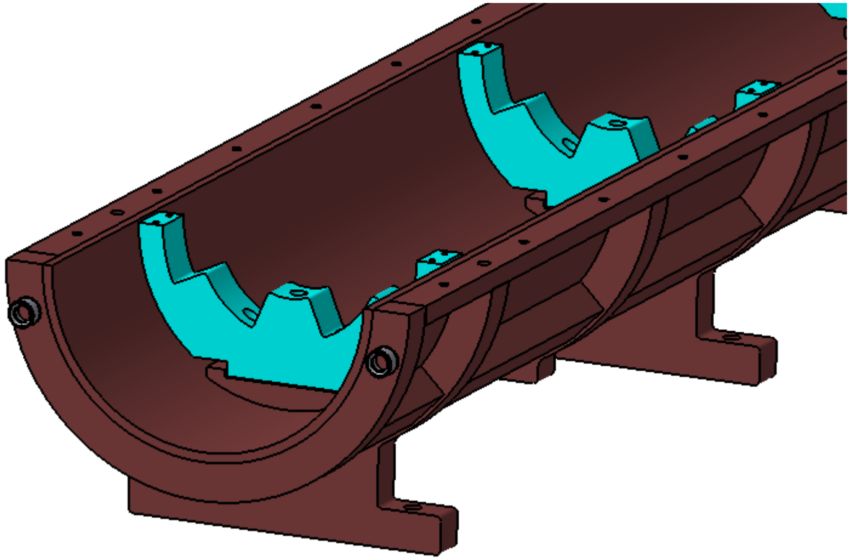
Design of the full-scale prototype CT coil dipole magnet

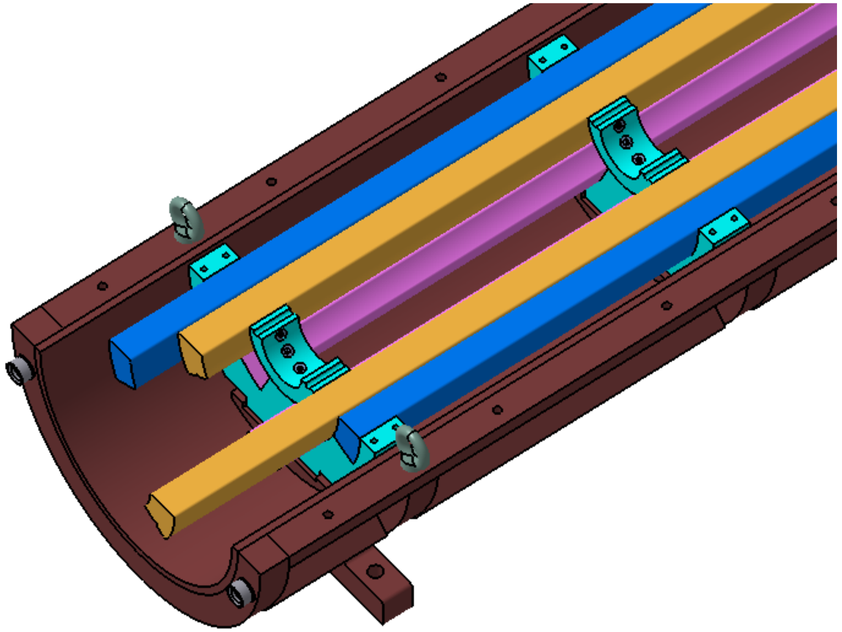
To control the size and position precision of the conductors, the supporters every 415mm in longitudinal direction are fabricated and assembled in the shielding tube.



Design of the full-scale prototype CT coil dipole magnet

The whole assembly of the magnet will be done in the shielding tube, which can be opened into upper and lower parts. The position of the shielding tube that support the supporters of the CT coils will be carefully and precisely machined.





Design of the full-scale prototype CT coil dipole magnet

The designed parameters of the CT coil dipole magnet

序号	BST-63B设计参数		序号	BST-63B设计参数		序号	BST-63B设计参数	
1	磁铁数量	1	18	电流[A]@10GeV	96	35	最大直流电压[V]@120GeV	1.1
2	磁铁气隙[mm]	63	19	平均电流[A]	733	36	感抗压降[mV]	79.7
3	磁场 [Gs]@180GeV	500	20	导线尺寸 [mm*mm]	I-A675R57-0-A248R13846	37	线圈R1[mm]	57
4	磁场 [Gs]@120GeV	338	21	导电截面[mm^2]	1973.2	38	线圈R2[mm]	100
5	磁场 [Gs]@10GeV	29	22	最大电流密度[A/mm^2]@120	0.59	39	线圈R3[mm]	138.46
6	磁有效长度 [mm]	4700	23	最大电流密度[A/mm^2]@180	0.9	40	线圈角度A1[°]	33.75
7	好场区宽度 [mm]	55	24	平均电流密度[A/mm^2]	0.37	41	线圈角度A2[°]	67.5
8	积分磁场均匀性	0.001	25	平均匝长[m]	11.00	42	线圈角度A3[°]	24.8
9	磁场上升时间[s]	4	26	单极导线长度[m]	33	43	线圈端部过桥长度[mm]	300
10	磁场平顶时间[s]	1	27	线圈导线总长[m]	66	44	线圈长度[mm]	4700
11	磁场下降时间[s]	4	28	直流电阻[mOhm]	0.94658	45	屏蔽筒内径[mm]	340
12	单极安匝数[At]@180GeV	5160	29	最大功耗[W]@180GeV	2800	46	屏蔽筒外径[mm]	360
13	单极安匝数[At]@120GeV	3477	30	最大功耗[W]@120GeV	1272	47	屏蔽筒重量[kg]	976
14	单极安匝数[At]@10GeV	288	31	平均功耗[W]@10-180GeV	1120	48	线圈重量[kg]	385
15	单极线圈匝数	3	32	平均功耗[W]@10-120GeV	510	49	磁铁总重[kg]	1400
16	电流[A]@180GeV	1720	33	电感[mH]	0.300	50	所有磁铁最大功耗[MW]]@120GeV	20.7
17	电流[A]@120GeV	1159	34	最大直流电压[V]@180GeV	1.8	51	所有磁铁平均功耗[MW]	8.3

Next stage working plan

- ✓ In the Jun. of 2021, complete the fabrication of the full scale CT coil prototype dipole magnet.
- ✓ In the Jun. of 2021, design and set up the field measurement system for the full scale magnet.
- ✓ In Aug. of 2021, complete the test of the full scale prototype dipole magnet.
- ✓ In Dec. of 2021, make the field quality of the magnet meet the specifications by modifying and improving the structure of the magnet.

Summary

- ✓ Two kinds of subscale prototype dipole magnets with and without iron cores were designed and fabricated.
- ✓ It is difficult to make the dipole magnet with iron cores to meet the precision requirement at low level of 28 Gs due to the unavoidable influence of the remnant field.
- ✓ The CT coil dipole magnet without iron cores has high precision and good reproducibility field both at low and high field level, which is satisfied with the requirements.
- ✓ The full-scale CT dipole magnet has been designed on the basis of the good test results of the subscale prototype magnet and will be fabricated in the Jun. of next year.

Thank you for your attention!