HL-LHC MCBRD CCT Magnets: Review and Latest Progress in China

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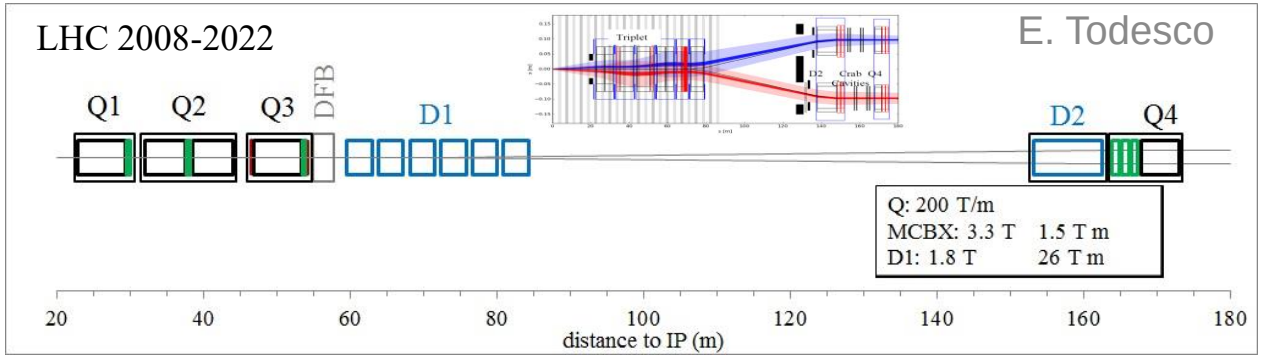
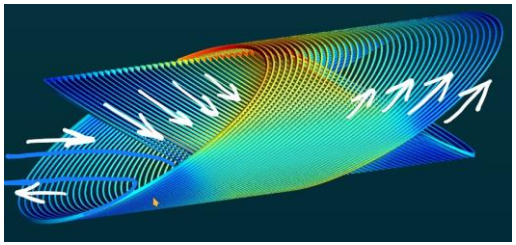
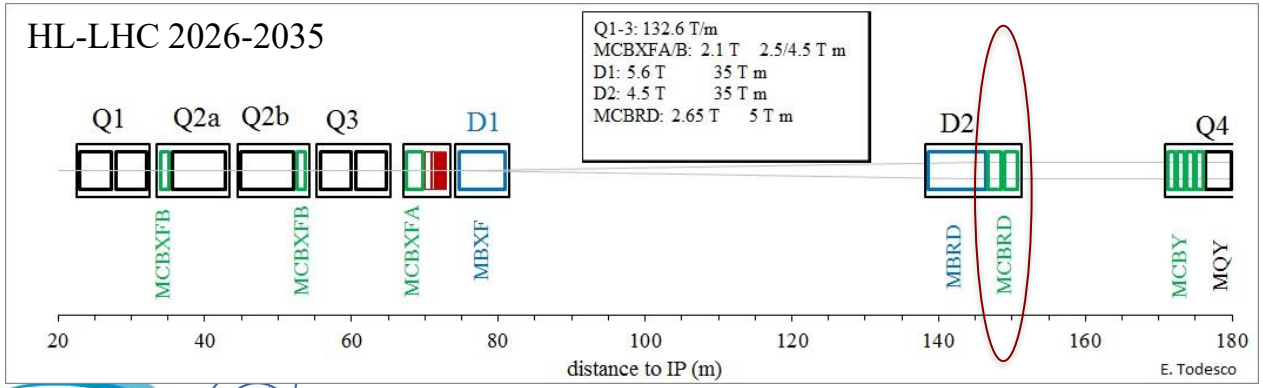
For the CCT Magnet Team

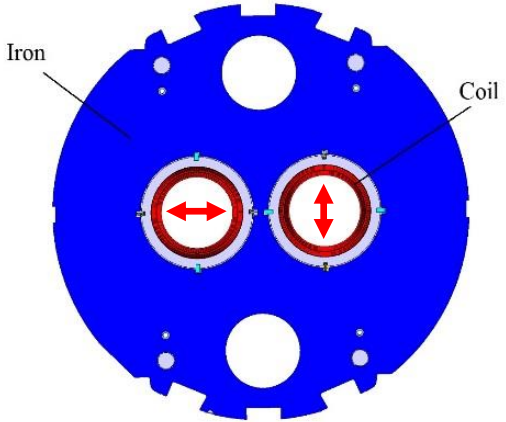
2023.05.10

MCBRD: the HL-LHC D2 orbit correctors, 12+1 units, providing a 5 Tm integrated field in two apertures, vertical in one and horizontal in the other.



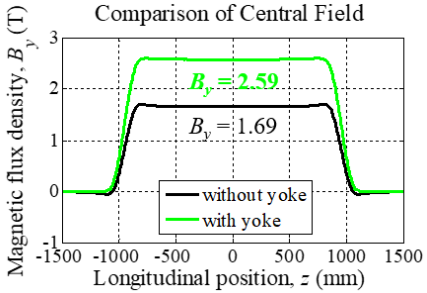


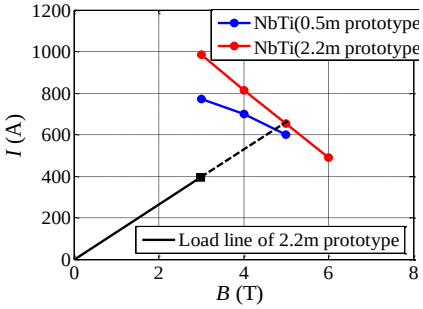


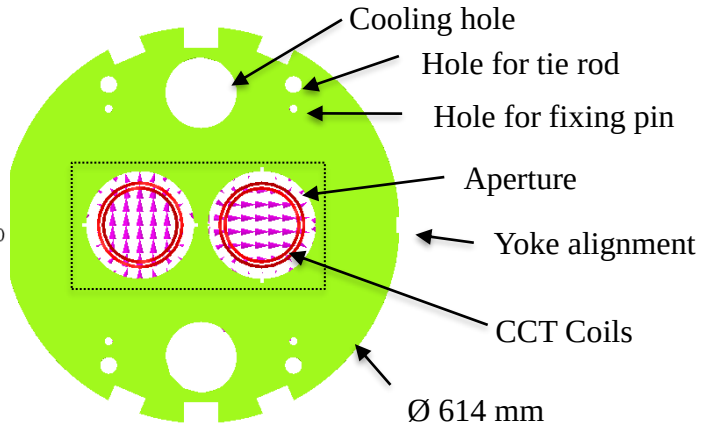


Main design parameters of the CCT magnet

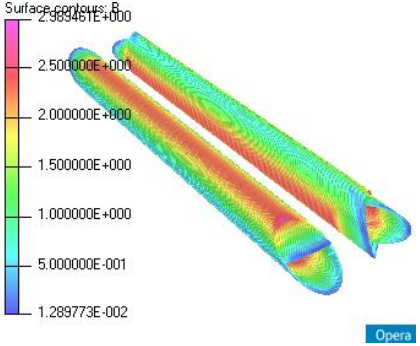
Items	Values
CCT skew angle	30°
No. of turns per layer	365
Slot size in former (mm)	2×5
Spacing per turn	5.222
Inside/Outside diameter of the former (mm)	Inner former:105.35/119.35 Inner former:120.80/134.85
Inside diameter of the groove/slot(mm)	1st layer: 109.15/119.15 2nd layer: 124.65/134.65
Reference radius (mm)	35
Diameter of aperture (mm)	105
Current (A)	395

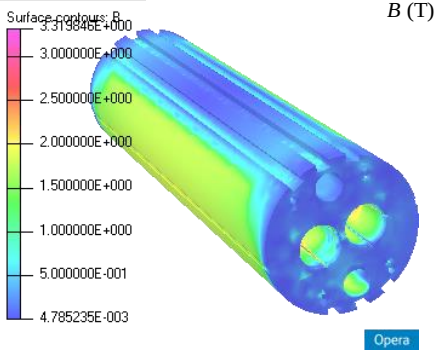






Items	Values
Diameter of yoke (mm)	614
Thickness of yoke lamination (mm)	5.8
Diameter of aperture (mm)	167
Position of aperture (mm)	94.19
Yoke key slot(mm)	8(3.01) ×6
Diameter of cooling hole (mm)	110
Position of cooling hole (mm)	205

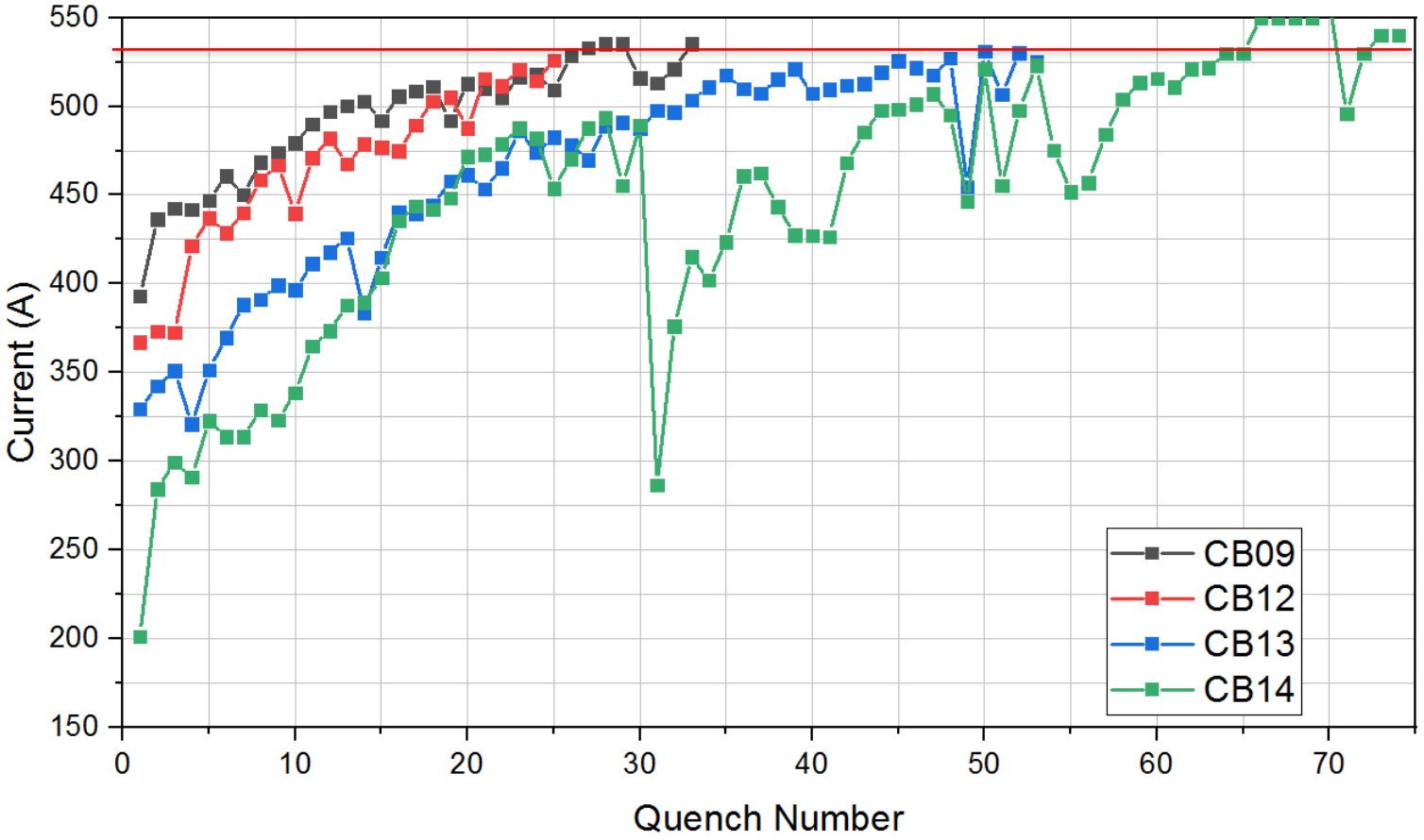




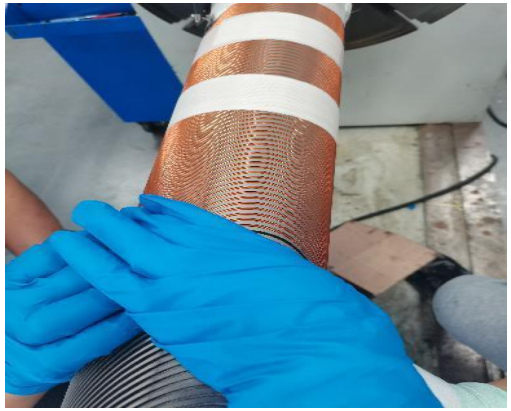
Progress of series production

	Coil name	Winding method	Location	Coil stand-alone performance (4.2 K)	Magnet performance at 4.2 K
Magnet1	MCBRD_CB01	Wet wind	CERN	530 A	Both apertures reached ultimate current 422 A, and passed 4-hour stability test
	MCBRD_CB03	Direct wind		410 A (training stopped due to the availability of the test station)	
	MCBRD_CB02	Direct wind	CERN	Failed to reach the design current	
Magnet2	MCBRD_CB04	Wet wind	CERN	422 A (training stopped due to the availability of the test station)	Both apertures reached ultimate current 422 A, and passed 4*1 hour stability test
	MCBRD_CB06	Wet wind		530 A	
Magnet3	MCBRD_CB09	Direct wind with new channel size	*Shipping to CERN*	530 A	Both apertures reached ultimate current 422 A, and passed stability test
	MCBRD_CB12	Direct wind with new channel size		526 A (25 quenches)	
	MCBRD_CB13	Direct wind with new channel size	BAMA	530 A (20+33 quenches)	-
	MCBRD_CB14	Direct wind with new channel size	BAMA	530 A (30+34 quenches), detraining problem, put in quarantine	-
	MCBRD_CB17	Direct wind with new channel size	BAMA	*Waiting for VPI*	-
MCBRD_CB10, 11, 15, 16		Shipped to CERN for fabrication			

Training-history of Bama coils CB09-14

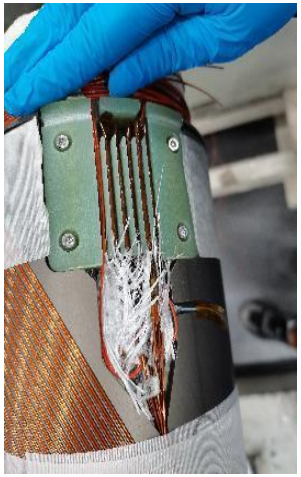


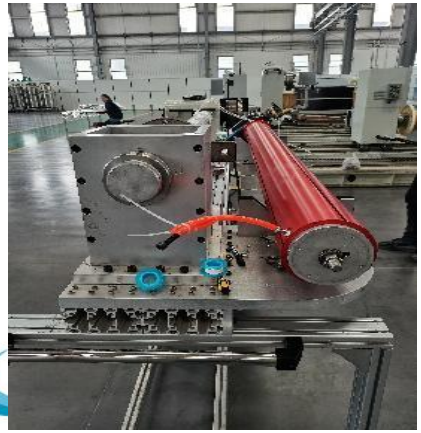
Manufacture of CB14

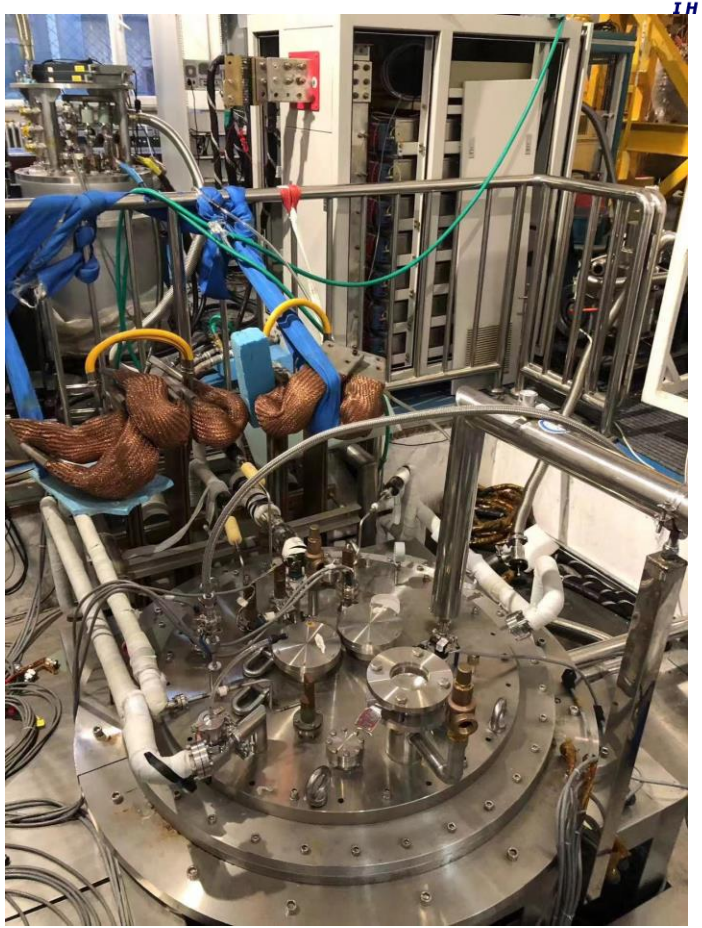



Manufacture of CB14

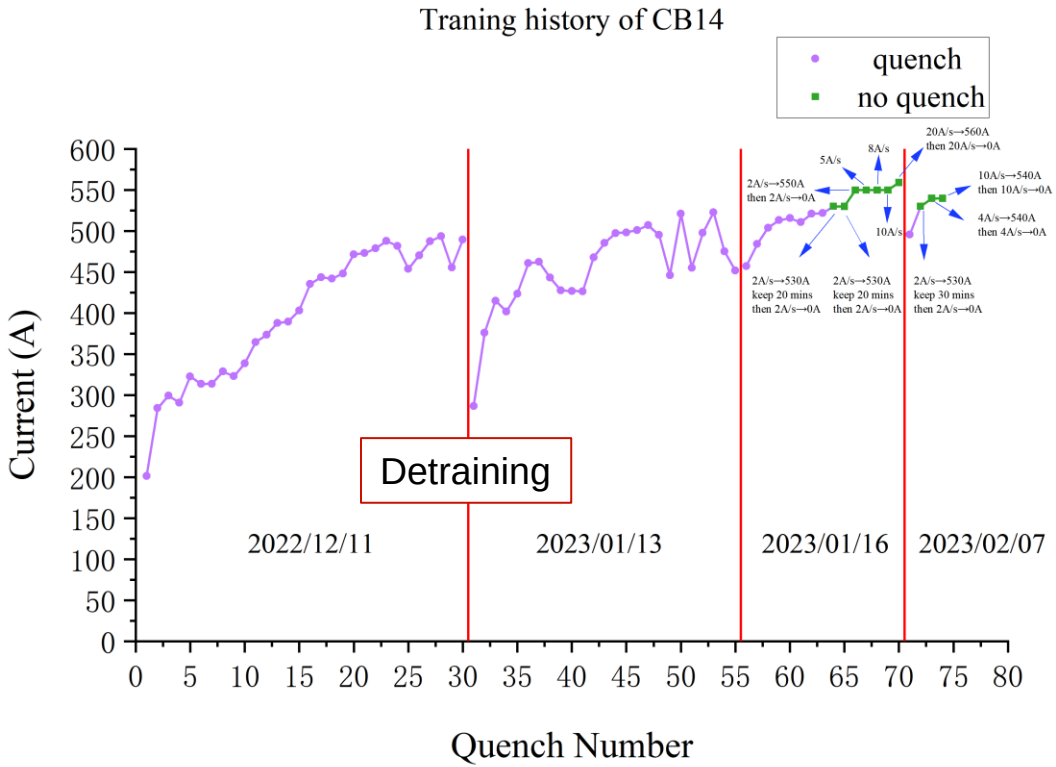




Stand-alone test of CB14 at IHEP



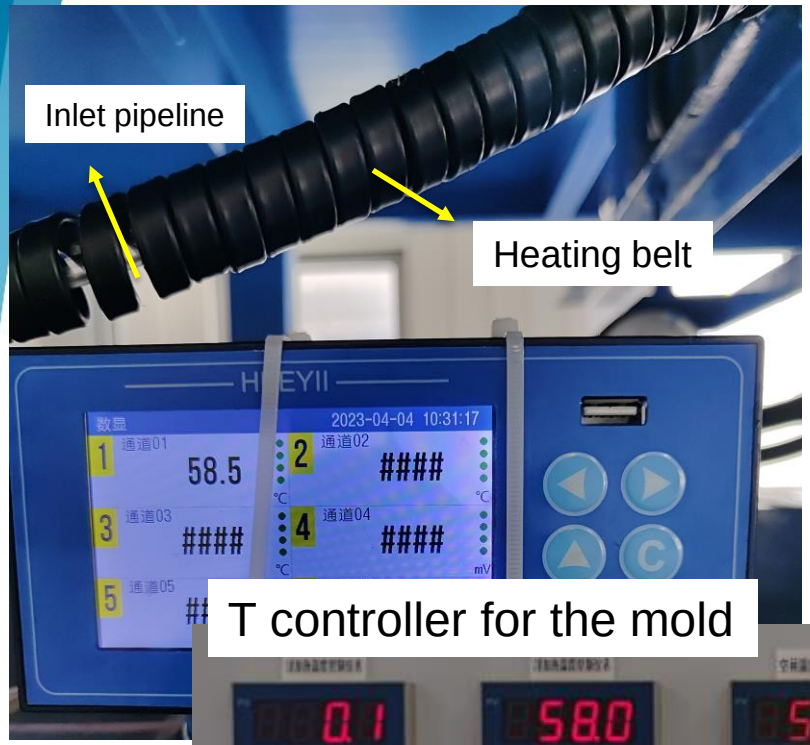
Stand-alone test of CB14

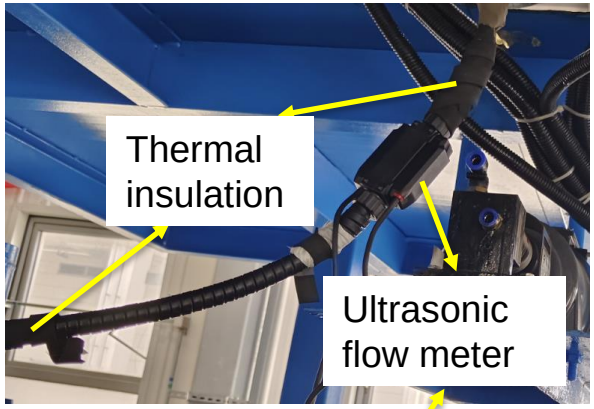


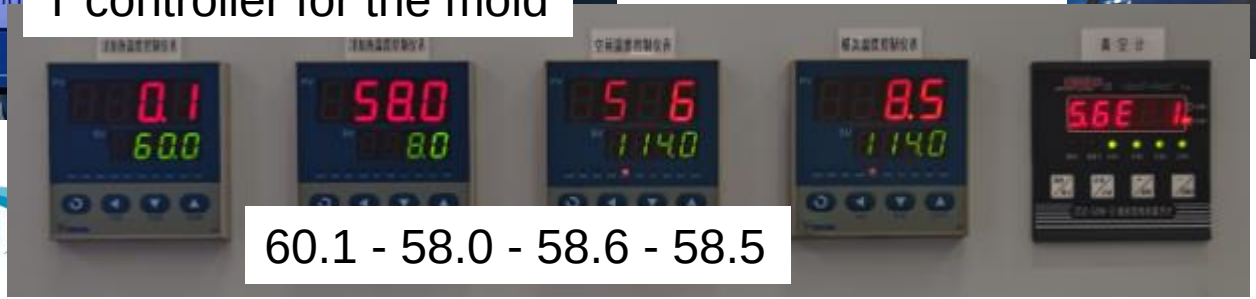
Changes:

- Changes of the operators.
- **The inlet pipeline between mix tank and impregnation furnace (exposed in the air ~10℃) didn't use any thermal insulation.**
- It takes a longer time (6~7h) of injection compared with CB09 ~ CB13 (3~4h).

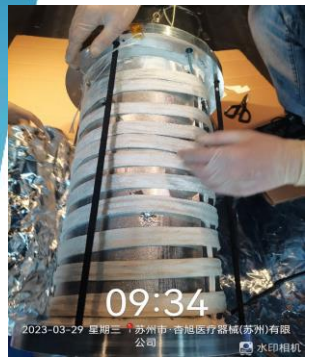
Corrective action of the VPI station

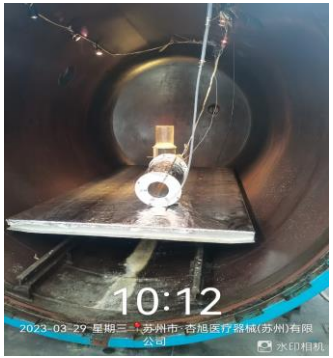






Qualification of the VPI system





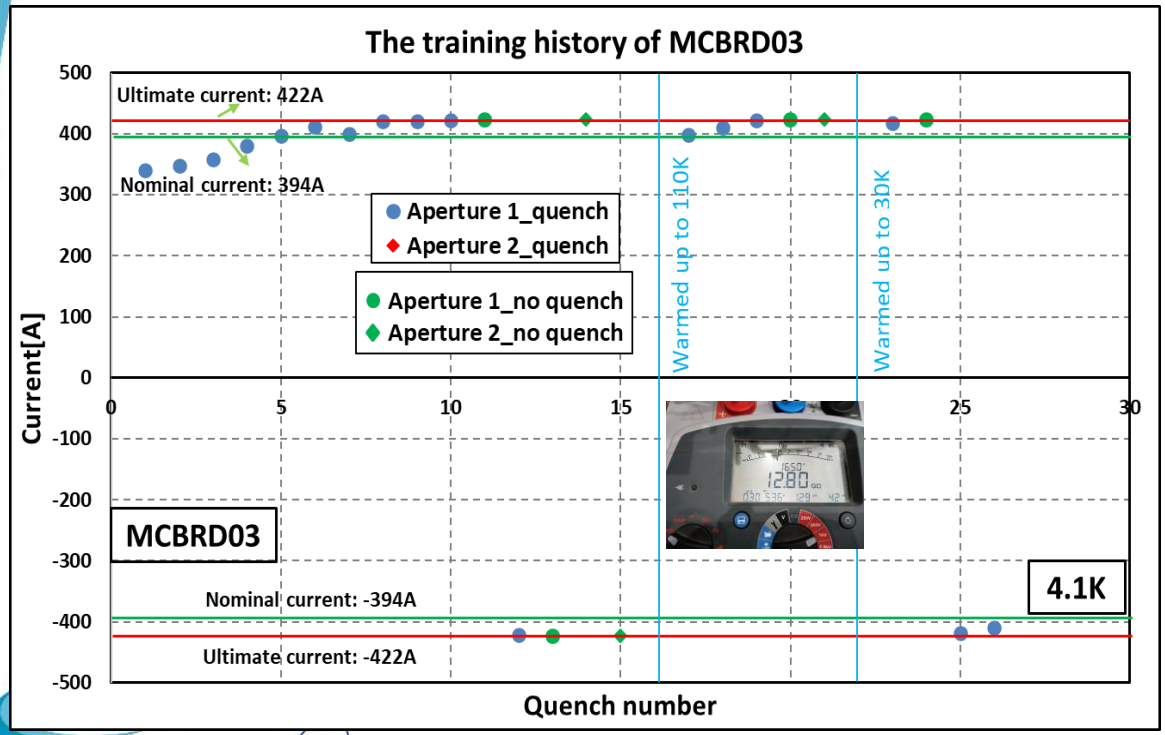
Set the curing procedure.
设定固化程序。

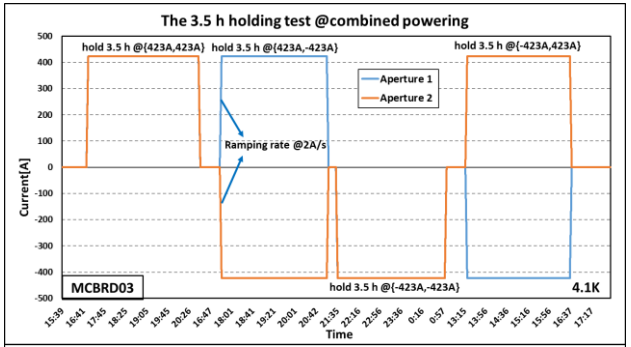
60℃ —30min→ 80℃ —1440min→ 80℃ —60min→ 135℃ —180min→ 135℃ → 20℃

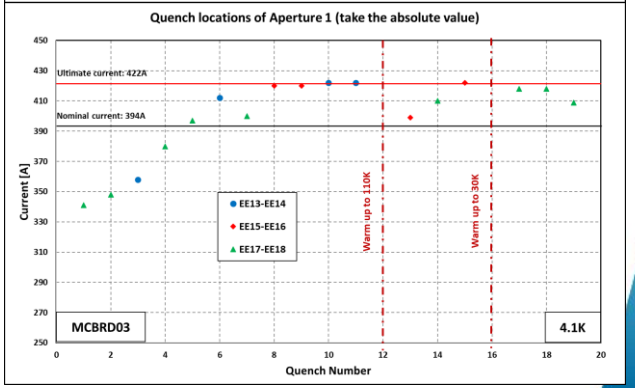
- We use a 0.5m quadrupole CCT magnet as a qualification of the VPI system after applying the corrective actions.
- This magnet will be tested this week.

Training history of MCBRD03 (1st test)

- AP1(CB12，25 quenches 526A) reached ±422A after 11 quenches.
- AP2(CB09, 33 quenches 530A; after thermal cycle ＞500A) reached ±422A without any quenches.

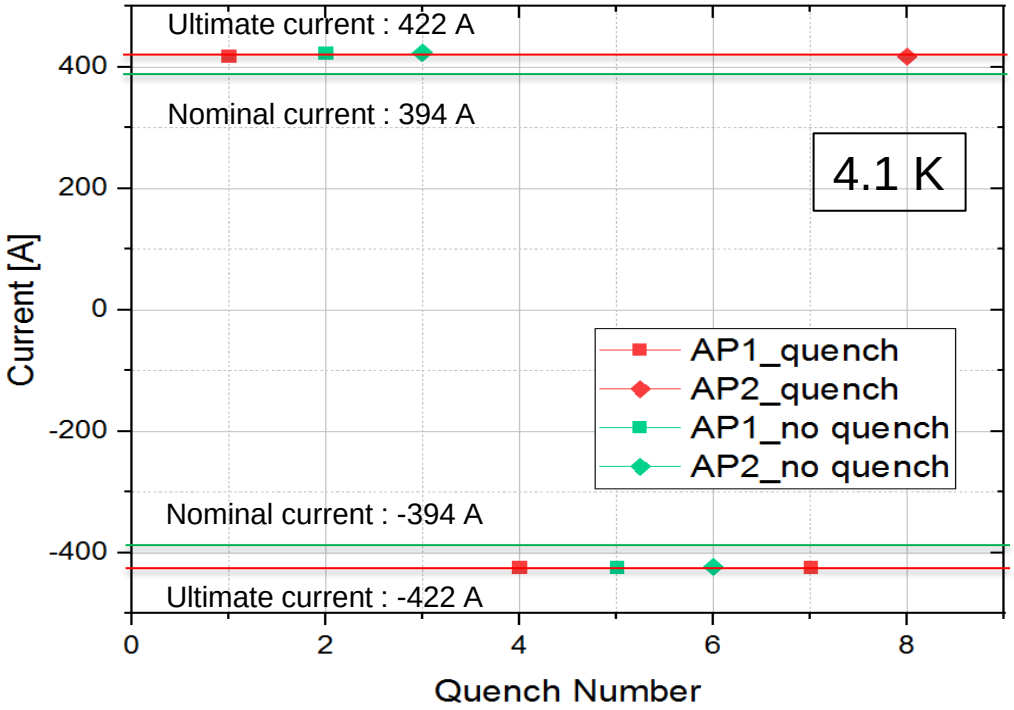


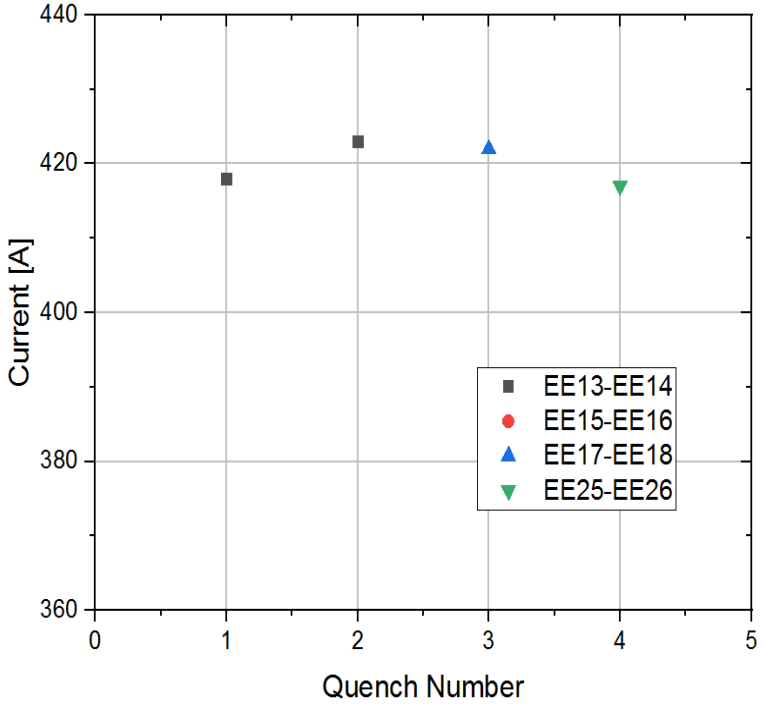




Training history of MCBRD03 (2nd test)

- Both Apertures reached the nominal current without any quenches after thermal cycle.

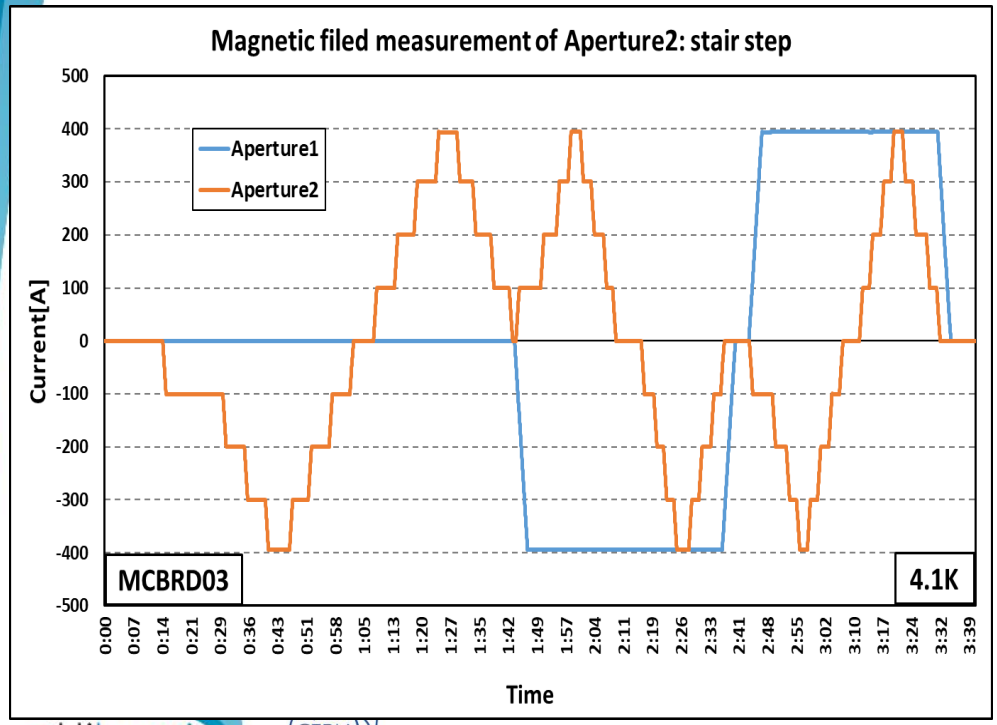




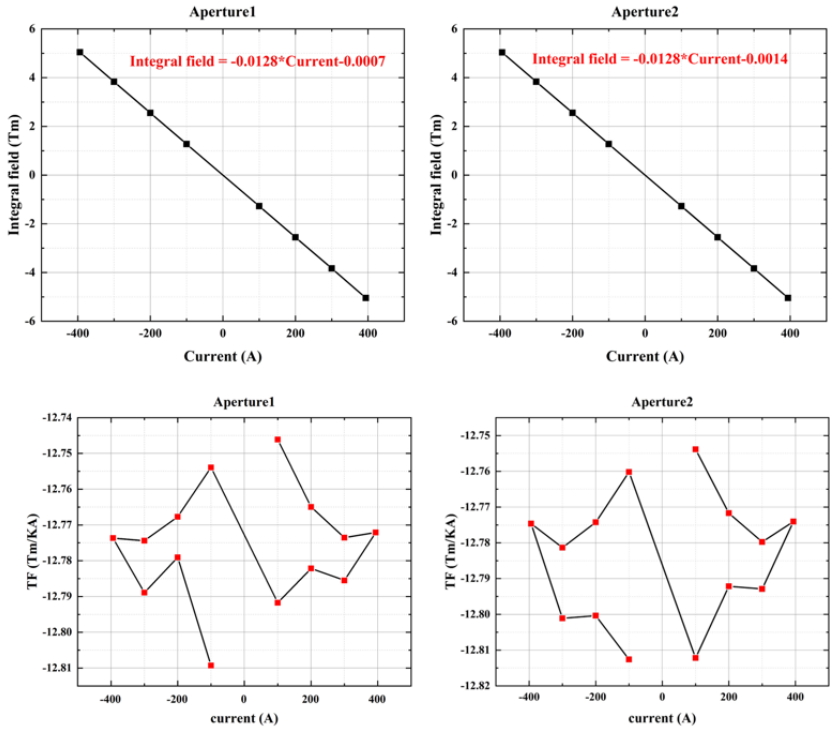
Training history and quench location of the 2nd test

Field Quality of MCBRD03

Stair steps & magnet filed measurement of Aperture 2 (MCBRD_CB09)

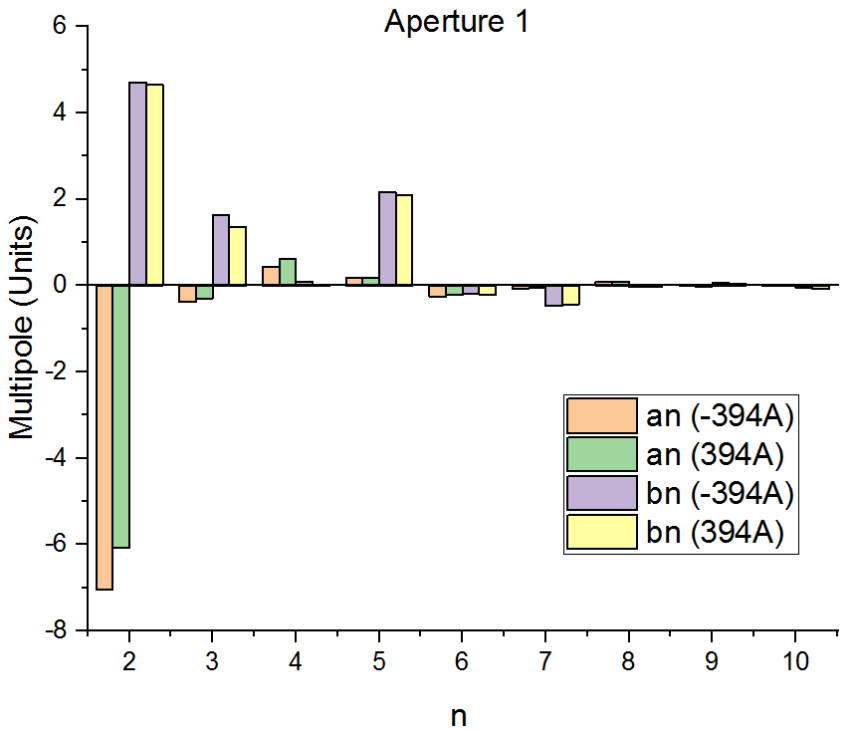


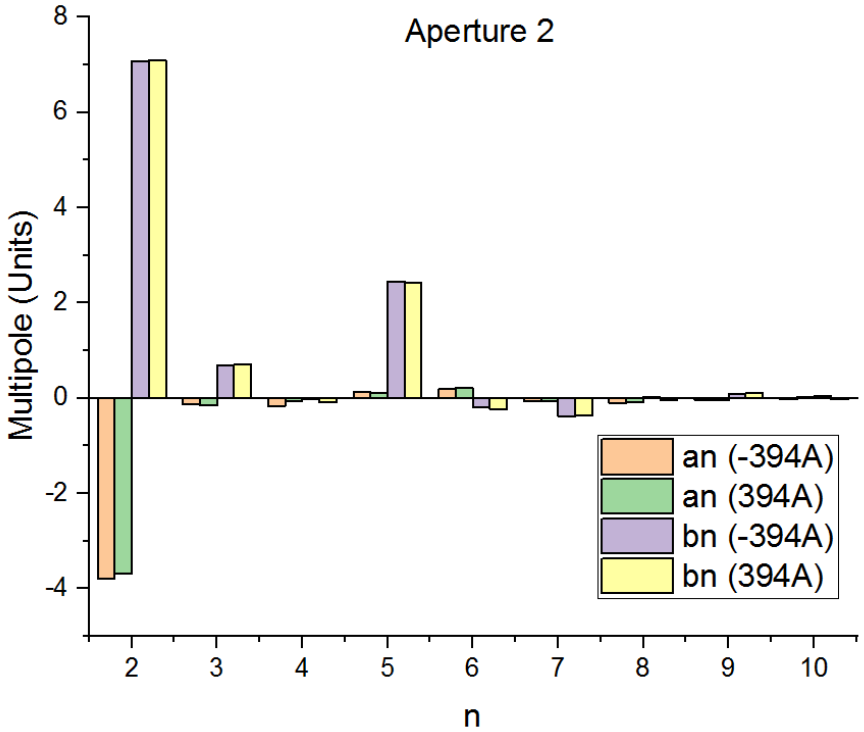
Integral Field and Transfer Function



Field Quality of MCBRD03

Multipoles (individual powering)





Multipoles –AP1 (individual powering)

Aperture 1 (MCBRD_CB12) @ ramping up								
	-100A		-200A		-300A		-394A	
n	an	bn	an	bn	an	bn	an	bn
2	-4.50040	2.13859	-5.19001	3.45314	-5.69287	4.14465	-7.03831	4.70526
3	0.42357	3.05241	0.18448	0.57213	-0.03520	1.13365	-0.37439	1.63961
4	0.69611	-0.30172	0.65365	-0.19803	0.53357	-0.14939	0.44021	0.08241
5	0.19717	2.55257	0.11417	1.83818	0.14957	1.74971	0.16902	2.15402
6	-0.19741	-0.10484	-0.20612	-0.14335	-0.18974	-0.15380	-0.25060	-0.20054
7	-0.03104	-0.05045	-0.05929	-0.26855	-0.07823	-0.32614	-0.07640	-0.47337
8	0.11026	-0.02358	0.08175	-0.02506	0.09058	0.00234	0.08240	-0.01950
9	0.00820	0.06000	-0.00708	0.02217	-0.02059	0.02763	0.00184	0.06223
10	0.00357	-0.03813	0.00631	-0.03708	0.01437	-0.03765	0.00618	-0.04837

Aperture 1 (MCBRD_CB12) @ ramping up								
	100A		200A		300A		394A	
n	an	bn	an	bn	an	bn	an	bn
2	-4.27368	4.38865	-4.76084	4.00735	-5.17860	4.17969	-6.07863	4.65889
3	0.36779	2.18547	0.15767	0.15551	-0.02551	0.83986	-0.30444	1.34324
4	0.74333	0.18810	0.59700	-0.02378	0.54989	-0.04978	0.62414	-0.00873
5	0.20771	2.49497	0.10856	1.78722	0.12524	1.70399	0.18207	2.09014
6	-0.15192	-0.06673	-0.17020	-0.10741	-0.19285	-0.15217	-0.21987	-0.20909
7	-0.03102	-0.06196	-0.03172	-0.24929	-0.04694	-0.33945	-0.05676	-0.43269
8	0.10576	-0.03406	0.09840	-0.02648	0.11139	-0.02338	0.09832	-0.03368
9	-0.00692	0.00781	-0.02450	-0.00030	-0.03826	0.01176	-0.02535	0.04364
10	-0.00104	-0.06223	0.01566	-0.03488	0.01173	-0.03651	0.01373	-0.07574

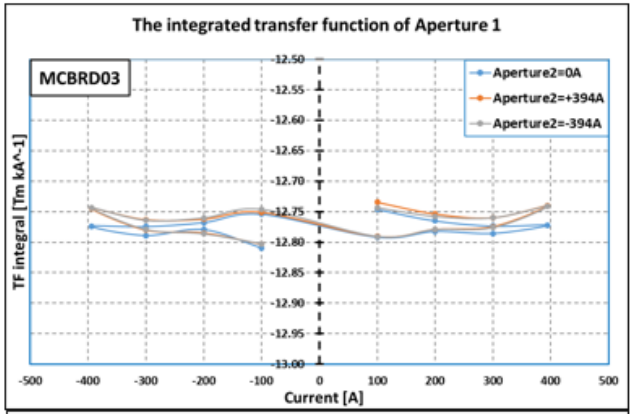
Multipoles –AP2 (individual powering)

Aperture 2 (MCBRD_CB09) @ ramping up								
	+100A		+200A		+300A		+394A	
n	an	bn	an	bn	an	bn	an	bn
2	0.51334	6.79305	0.61303	6.74085	-0.23368	6.94466	-3.68201	7.08871
3	0.45030	2.16348	0.22338	0.15573	0.05082	1.11222	-0.15213	0.71026
4	-0.43018	0.07183	-0.24788	-0.01038	-0.16346	-0.03915	-0.07066	-0.07836
5	0.21841	2.63806	0.13708	1.99150	0.14264	1.97349	0.11056	2.43106
6	0.06052	-0.13307	0.09526	-0.18572	0.12340	-0.20998	0.21066	-0.22405
7	0.00995	-0.02104	-0.00808	-0.20955	-0.04935	-0.28444	-0.05895	-0.36796
8	-0.06597	-0.04159	-0.04817	-0.02937	-0.04165	-0.03832	-0.07723	-0.04529
9	-0.03095	0.08791	-0.03611	0.04426	-0.04073	0.05505	-0.04554	0.10164
10	-0.04532	0.01203	-0.00950	0.00659	0.00633	0.00578	0.02094	-0.02666

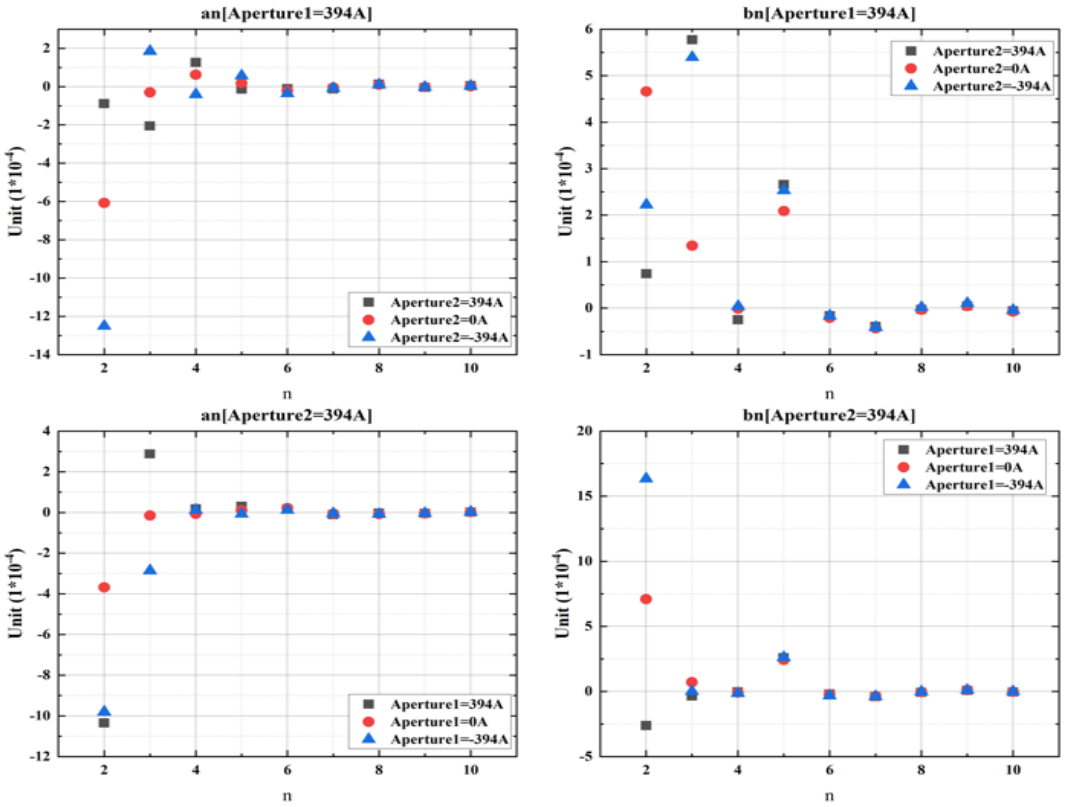
Aperture 2 (MCBRD_CB09) @ ramping up								
	-100A		-200A		-300A		-394A	
n	an	bn	an	bn	an	bn	an	bn
2	0.50806	6.94348	0.53457	6.81459	-0.22350	6.84083	-3.79837	7.06555
3	0.40866	2.33744	0.21651	0.12295	0.05553	0.99451	-0.12747	0.69508
4	-0.42887	0.13706	-0.22545	0.09656	-0.27681	-0.00620	-0.16837	-0.01531
5	0.21136	2.60452	0.16334	2.04470	0.14316	2.02251	0.13484	2.45293
6	0.07233	-0.14474	0.11447	-0.19324	0.15643	-0.20411	0.19943	-0.18717
7	-0.00372	-0.09899	-0.00102	-0.23372	-0.02910	-0.29176	-0.05522	-0.38597
8	-0.07444	-0.01502	-0.02921	-0.01717	-0.05957	-0.01806	-0.10929	0.01936
9	-0.02501	0.02681	-0.02942	0.05095	-0.04431	0.04024	-0.03427	0.08583
10	0.05695	0.03257	0.00114	0.02397	0.00025	0.03355	-0.02465	0.04118

Field Quality of MCBRD03

Crosstalk-transfer function (combined powering)



Crosstalk- Multipoles (combined powering)



Crosstalk-transfer function (combined powering)

Aperture1[A]	Aperture2[A]			Aperture2[A]	Aperture1[A]		
	0	+394	-394		0	+394	-394
100	-12.74612	-12.73445	-12.74309	100	-12.75385	-12.75027	-12.75106
200	-12.76495	-12.75368	-12.75757	200	-12.77169	-12.76685	-12.77325
300	-12.77356	-12.75995	-12.75994	300	-12.77974	-12.76914	-12.76993
394	-12.77209	-12.74035	-12.74116	394	-12.77406	-12.75245	-12.74987
300	-12.78550	-12.77455	-12.77610	300	-12.79290	-12.78426	-12.78461
200	-12.78216	-12.77885	-12.77919	200	-12.79216	-12.78834	-12.78916
100	-12.79174	-12.79051	-12.79057	100	-12.81219	-12.80341	-12.80296
-100	-12.75393	-12.75110	-12.74580	-100	-12.76019	-12.75610	-12.75203
-200	-12.76771	-12.76220	-12.76016	-200	-12.77425	-12.77341	-12.76705
-300	-12.77440	-12.76306	-12.76396	-300	-12.78133	-12.76898	-12.76940
-394	-12.77367	-12.74435	-12.74318	-394	-12.77462	-12.75280	-12.75145
-300	-12.78892	-12.78000	-12.77920	-300	-12.80112	-12.78394	-12.78416
-200	-12.77904	-12.78471	-12.78618	-200	-12.80038	-12.78889	-12.78942
-100	-12.80929	-12.80321	-12.80262	-100	-12.81261	-12.80343	-12.80335

Crosstalk-Multipoles (combined powering)

	Aperture 1 (MCBRD_CB12) at 394A					
Aperture2[A]	0A		394		-394	
n	an	bn	an	bn	an	bn
2	-6.07863	4.65889	8.13214	-6.81124	-12.50908	2.22331
3	-0.30444	1.34324	-1.21701	8.59996	1.84462	5.39625
4	0.62414	-0.00873	0.50878	0.27393	-0.40927	0.04036
5	0.18207	2.09014	-0.18451	2.47873	0.56530	2.53141
6	-0.21987	-0.20909	0.15336	0.15714	-0.35529	-0.16529
7	-0.05676	-0.43269	-0.24873	0.01071	-0.08740	-0.41142
8	0.09832	-0.03368	-0.12367	-0.20674	0.09972	0.01695
9	-0.02535	0.04364	0.24268	-0.02647	-0.03161	0.10476
10	0.01373	-0.07574	0.28325	0.20327	0.03408	-0.04311

	Aperture 2 (MCBRD_CB09) at 394A					
Aperture1[A]	0A		394		-394	
n	an	bn	an	bn	an	bn
2	-3.68201	7.08871	-10.34655	-2.62457	-9.80432	16.34188
3	-0.15213	0.71026	2.87709	-0.34995	-2.86050	0.00720
4	-0.07066	-0.07836	0.17573	-0.02580	0.11868	-0.14828
5	0.11056	2.43106	0.29614	2.59239	-0.07203	2.61698
6	0.21066	-0.22405	0.16676	-0.19371	0.12004	-0.32182
7	-0.05895	-0.36796	-0.10420	-0.39263	-0.05007	-0.37748
8	-0.07723	-0.04529	-0.03795	-0.07794	-0.08337	-0.02172
9	-0.04554	0.10164	-0.04821	0.08660	-0.03792	0.10154
10	0.02094	-0.02666	0.01740	-0.04619	0.02038	-0.00807

Summary

- 3 series CCT magnets have been fabricated. All of them reached the ultimate current and passed the field quality test. The 4th magnet is under fabrication.
- Reasons for the detraining problem of CB14 have been found and about to be solved.
- Components for 2 CCT magnets have been shipped to CERN from IHEP, to verify the performance with components from China and CERN fabrication process.
- Shipment of MCBRD03 and yoke laminations for 1 CCT magnet will reach CERN in the middle of June.

Thanks for your attention