Activities on MCBXFB magnets at CERN

J. C. Pérez

CERN TE-MSC-SMT

On behalf of MCBXF team.

Acknowledgments to people who contribute to this presentation.

12th HL-LHC Collaboration Meeting - Uppsala-Sweden

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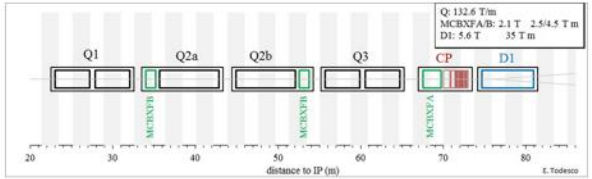
Outline

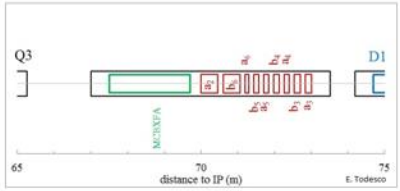
- MCBXF project
- Remind of MCBXFB01 & MCBXFBP2b performance
- Coils shiming and instrumentation during assembly
- MCBXFBP2c powering tests results & magnetic measurements
- Summary

MCBXF combined dipole orbit correctors for HL-LHC

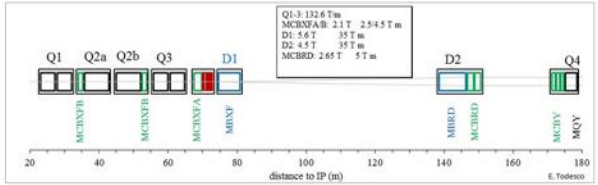
Insertion Region Layout

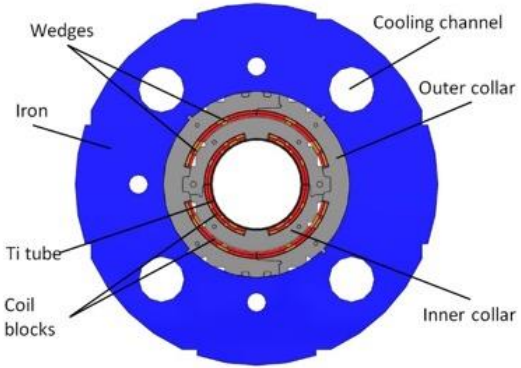


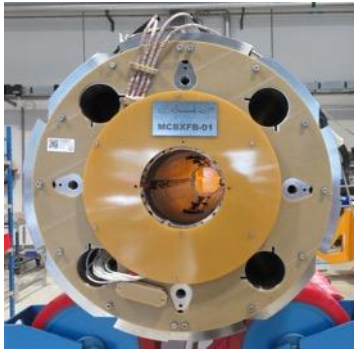
Magnification of the area around correctors:



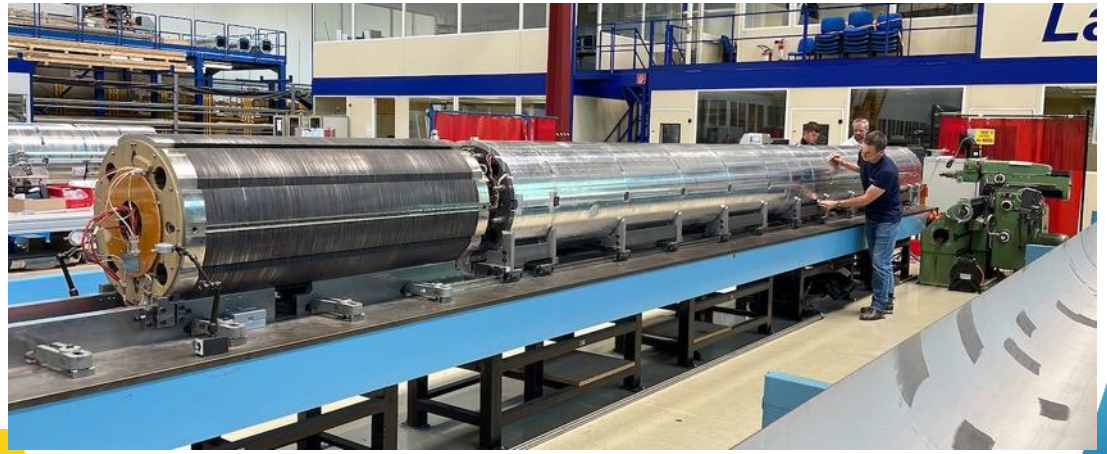
The layout up to Q4:





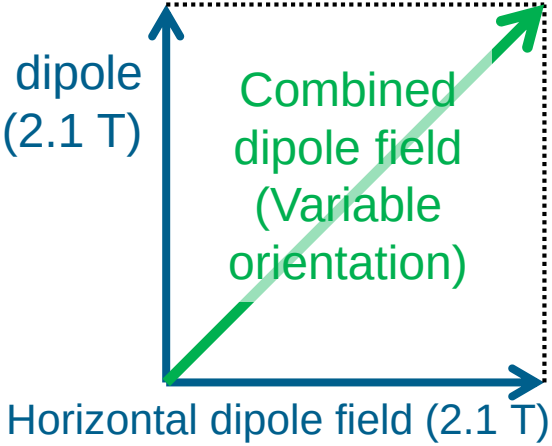


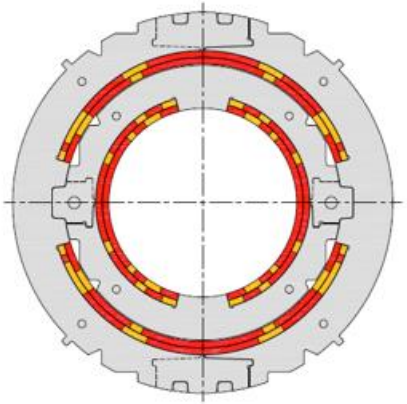
Q2 type Cold Mass assembly in LMF



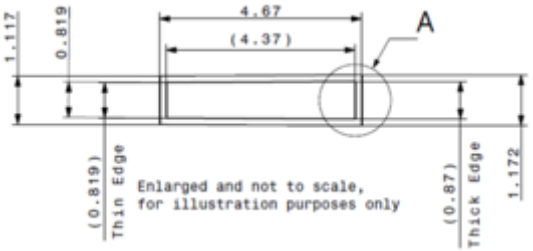
Magnet and cable specifications

MCBXFB Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	2.5 Tm
Minimum free aperture	150 mm
Nominal current	< 2500 A
Radiation resistance	35 MGy
Physical length	< 1.505 m
Working temperature	1.9 K
Iron geometry	MQXF iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)





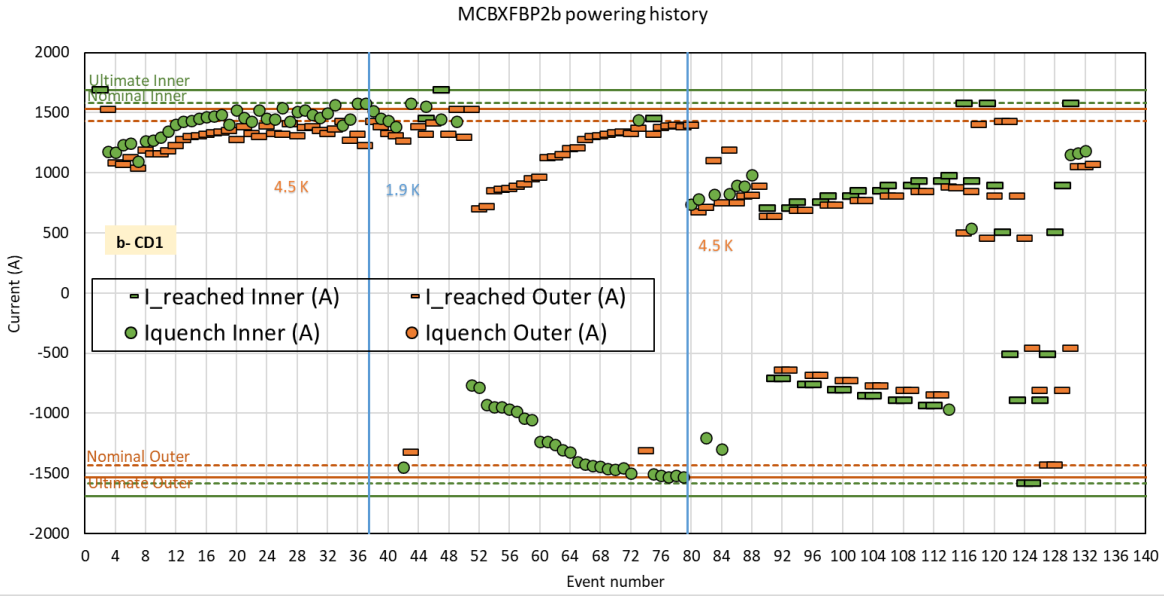
Cable Parameters	
No. of strands	18
Strand diameter	0.48 mm
Cable thickness	0.845 mm
Cable width	4.37 mm
Key-stone angle	0.67º
Cu:Sc	1.75

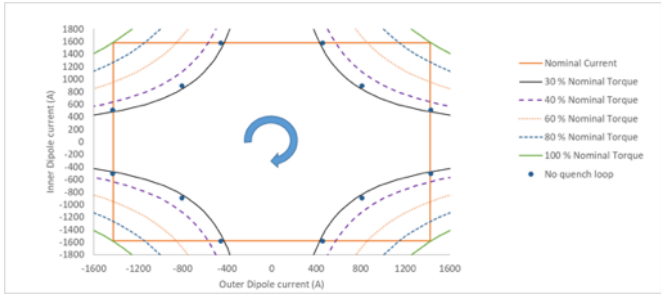


MCBXF project

- The MCBXF combined orbit corrector magnets contract for the series was signed with ELYTT Energy in March 2021
- 6 MCBXFA & 11 MCBXB magnets to be produced before end 2024
- The first 3 MCBXFB magnets have been produced within a close collaboration of CERN and CIEMAT teams (MCBXFBP1, MCBXFBP2 & MCBXFB01)
  - Coils and magnet components fabricated at CEDEX (Madrid)
  - Magnet assembly, WMM and cold powering tests performed at CERN
- The first MCBXFA prototype will be manufactured following the same organization

MCBXFBP2b powering history





Quench free area

Quench free cycle attempt of 12 points at 35%, quench when ramping the outer to nominal current.

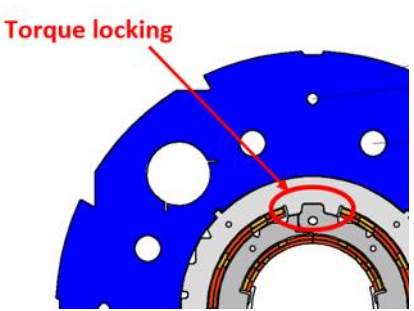
- Reached ultimate in both circuits in standalone
- 132 Events and 85 quenchs
- Reached 99.9% + nominal torque and 94.4% of -nominal torque

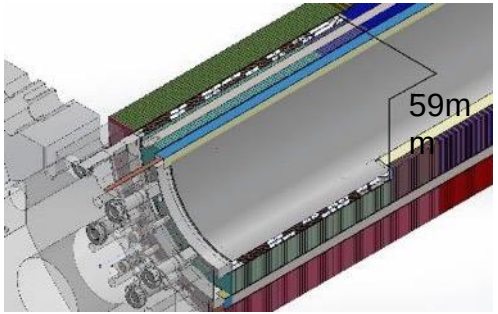
	Training quenches		
	IC4	IC5	OC3
	9 (10%)	76 (90%)	0
Total	85		

Quench free cycle of 12 points at 32% OK

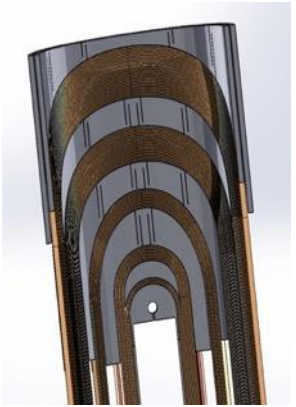
Modification of the inner dipole coil length from MCBXFB01

- Torque locking is only posible along the OD pole window (828 mm long)
- ID pole window for prototypes was 946 mm long → 59 mm at each side of the coil without torque locking
- The inner coil lenght was reduced by 118 mm
- The cantilever length of the inner coils was reduced by 59 mm at each coil extremity
- The inner coil nominal current was increased from 1625 A to 1755 A to keep the same integrated field (model discrepancy wrt to MM + straight section reduction)
- +5% of torque generated in the coil straight section





P1&P2



B01

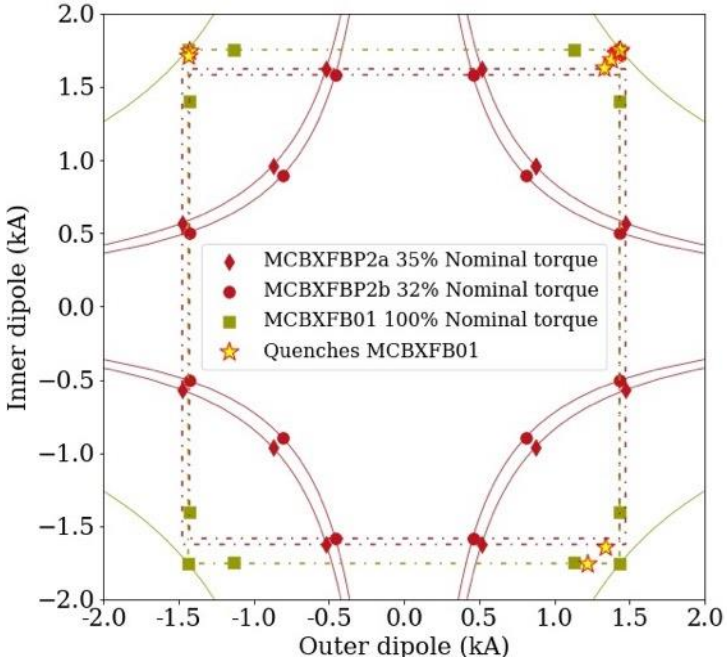
Reminder: MCBXFB01 performance

B01 showed **an excellent performance**:

- Ultimate current in both dipoles w/o quench in standalone configuration.
- Virgin **training reduced** to 3 quenches.
- Reached nominal in Q1 and Q2 no matter the powering sequence. **Without re-training**
- **Quench-free region** improved to **100%** of nominal torque.

After thermal cycle:

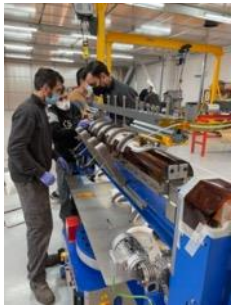
- **Good memory:** few quenches during the tests, very close to nominal torque in combined operation.
- Complete set of **magnetic measurements:** test results very close to calculations, within magnet specifications.

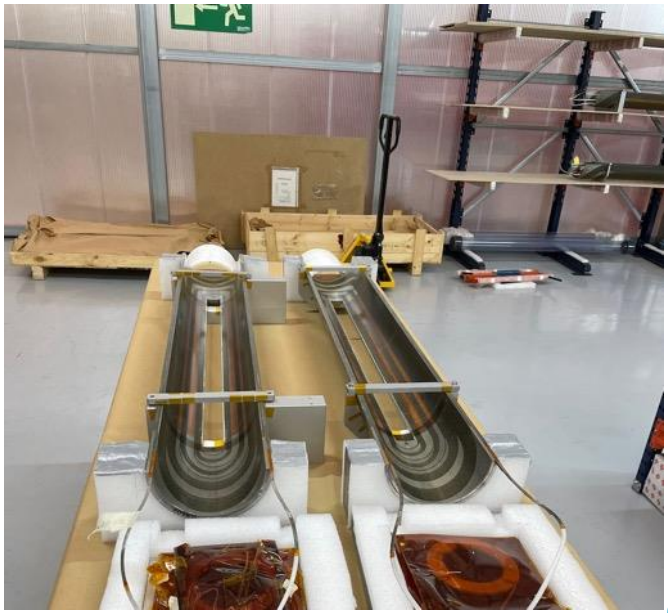


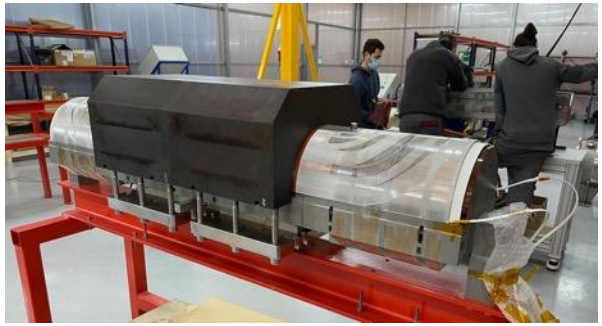
Courtesy S.Ferradas (CERN)

Test Results: https://edms.cern.ch/document/2618334/0.1

Inner coils for MCBXFBP2c manufacturing @ ELYTT



- The 2 inner coils used for MCBXBBP2c assembly have been produced at ELYTT's premises.
- The assembly of these coils in a magnet was foreseen to provide an "early" qualification of the coil fabrication process for the series
- The same outer coils used during MCBXFBP2b assembly have been assembled in MCBXFBP2c

Coils geometry & Shimming configuration

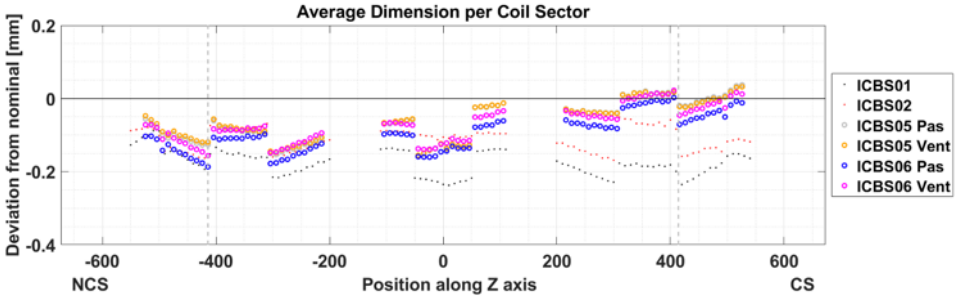


Figure 1. Deviation from nominal dimension per coil sector of MCBXFB short inner dipole coils.

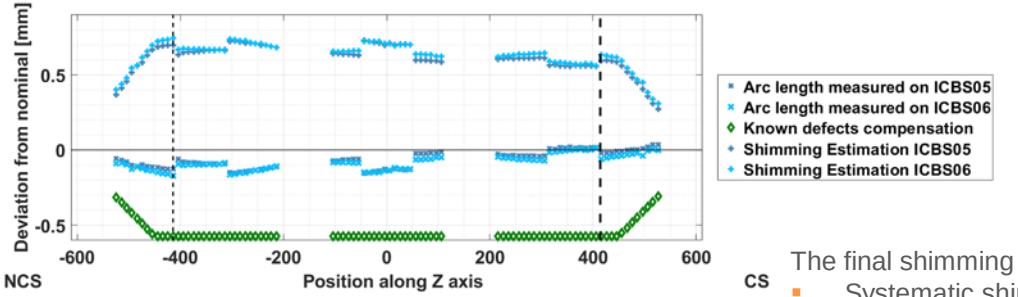
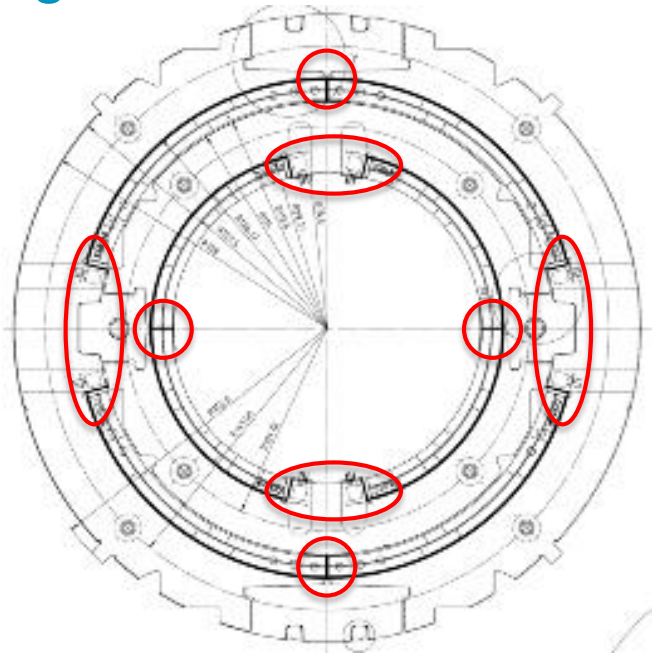


Figure 2.Shimming estimation for MCBXFBP2C coils.



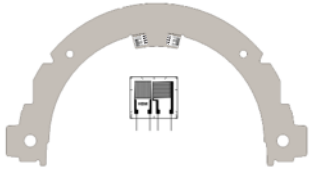
The final shimming configuration includes:

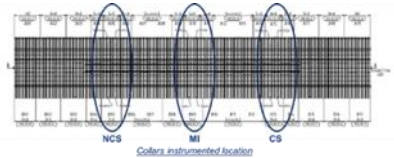
- Systematic shims part of the initial design
- Compensation of coil modulus of elasticity used during calculations
- Compensation of the thermal contraction coefficient used for calculations
- Compensation of coil geometrical deviation from nominal size
- Additional shims to achieve the nominal azimuthal pre-compression

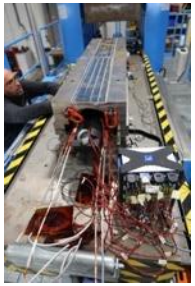
Mechanical measurements with instrumented collars during assembly

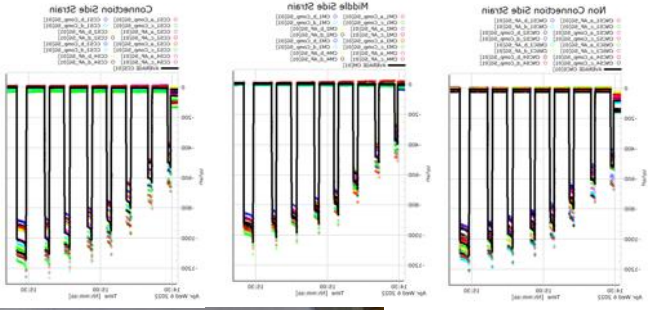
Equipment	Reference
Strain gauges	HBM: 1-XC11-1.5/350
Bridge power supply	2.5 V @ 1,2 kHz
Bridge Configuration	Half bridge – Poisson compensation
Quantity (Used during collaring process)	12 collars INNER 12 collars OUTER

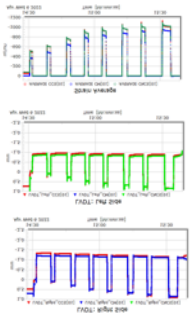
Strain gauges a & c are on the same side of the collar, b & d are on the other side

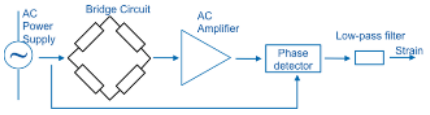












- The instrumented collar packs, are used during collaring operation as a measuring tool before the final collaring.
- They validate the tailored shims configuration built to provide the required pre-stress to the coils at room temperature

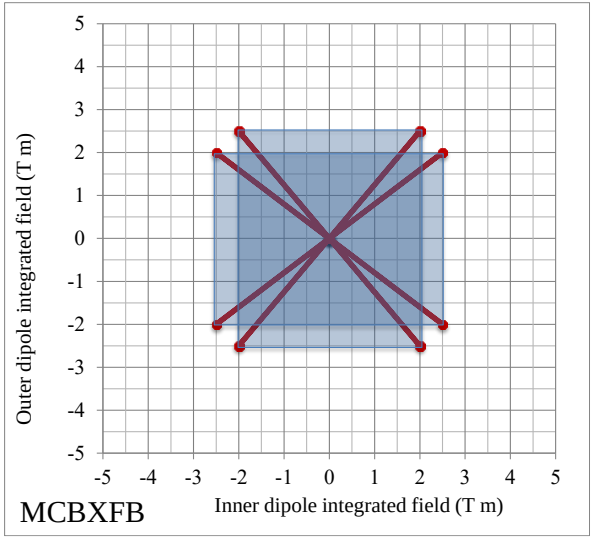
MCBXFBP2c: Acceptance criteria & Cold Powering tests results

Update of MCBXF correctors acceptance criteria

- The magnets shall provide the integrated field given in Table I, each one in two possible configurations.
- According to the HL-LHC guidelines, we define the nominal integrated field as the requirement for proton (or ion) operation at 7 TeV, and ultimate integrated field as the requirement for proton (or ion) operation at 7.5 TeV.

		Integrated field (T m)	
		Nominal	Ultimate
MCBXFA configuration 1	MCBXFA inner	4.500	4.821
	MCBXFA outer	2.500	2.678
MCBXFA configuration 2	MCBXFA inner	2.500	2.678
	MCBXFA outer	4.500	4.821
MCBXFB configuration 1	MCBXFB inner	2.500	2.678
	MCBXFB outer	2.000	2.143
MCBXFB configuration 2	MCBXFB inner	2.000	2.143
	MCBXFB outer	2.500	2.678

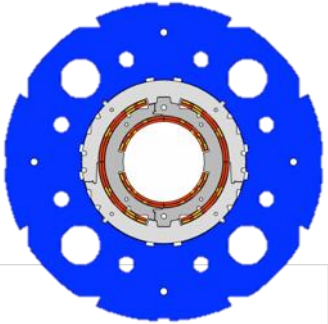
Integrated field and reference values for the current

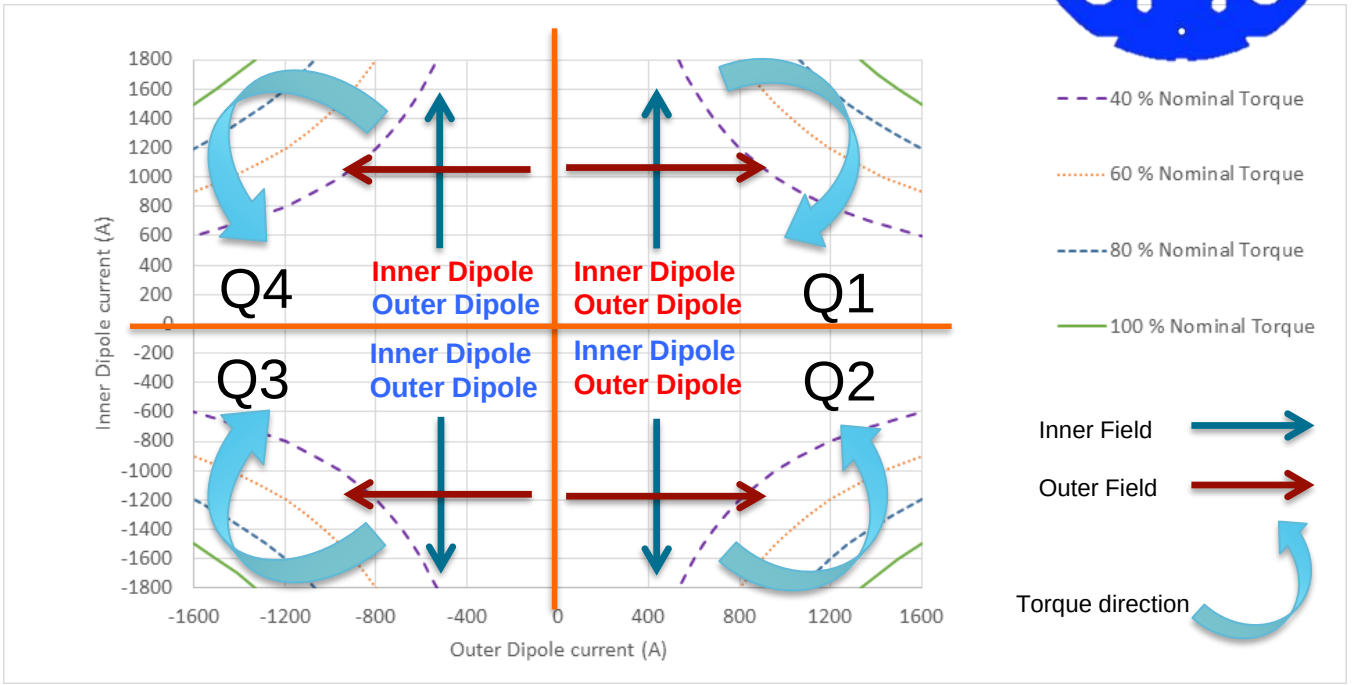


Required operational range of MCBXFB at 7 TeV

MCBXF Powering

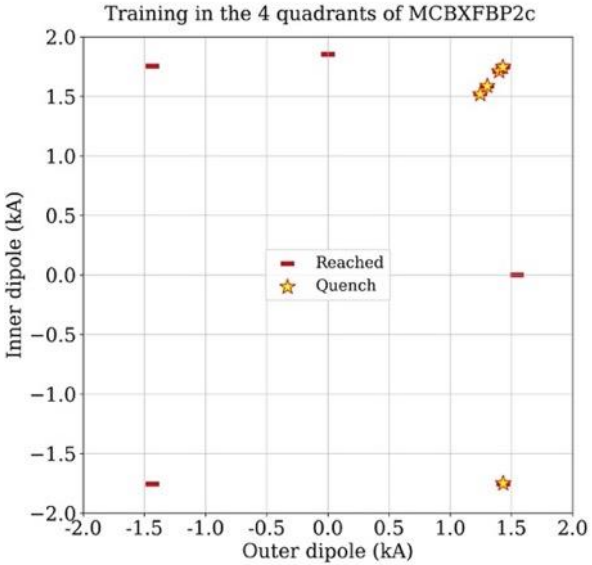
Nominal torque per unit length at straight section is very high: 147 kNm/m, about 84 MPa at the inner dipole coil.





MCBXBP2c training in the 4 quadrants to compare with previous magnets. Virgin inner dipole coils from Elytt

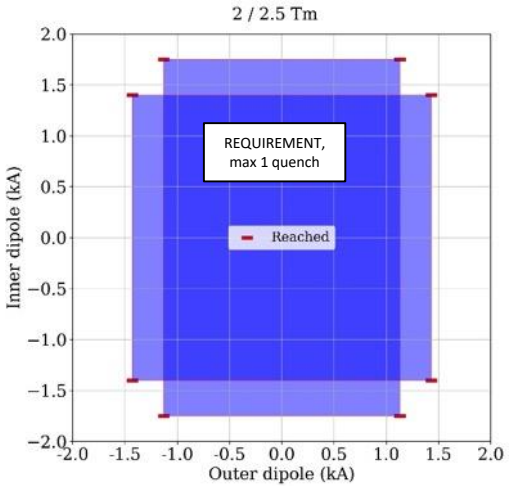
- Nominal current: Inner dipole 1755 A / Outer Dipole 1535 A
- Nominal ramp rate (5.5/4.5 A/s)
- No quenches in standalone powering up to ultimate current
- 3 training quenches to +nominal/+nominal in combined powering. (MCBXBP2a took 32 quenches, B01 took 3 quenches)
- No quenches to -nominal/-nominal (Same as B01)
- (!) No quenches to -nominal/+nominal in combined powering (1 quench in B01)
- 1 quench at -1749A/1433 A (same amount and same current level as B01). Then reached +nominal/-nominal
- 1 quench at 1588A/1302 A. Then reached +nominal/+nominal

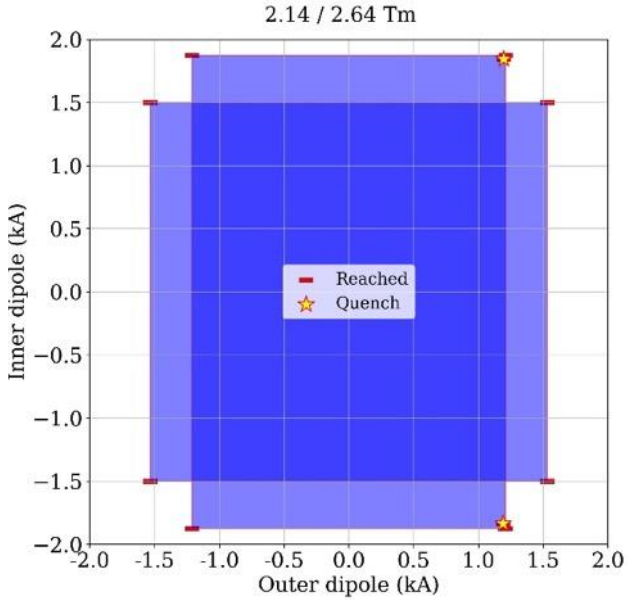


Courtesy of S. Ferradas

MCBXFBP2c Quench free working area in the four quadrants for a given integrated field

- Max ramp rate (5 A/s)
- No quenches in 2 / 2.5 Tm cycle
- 2 quenches in the inner dipole at almost ultimate current in the 2.14/2.64 Tm
- After the quench the ramp was restarted and successfully performed

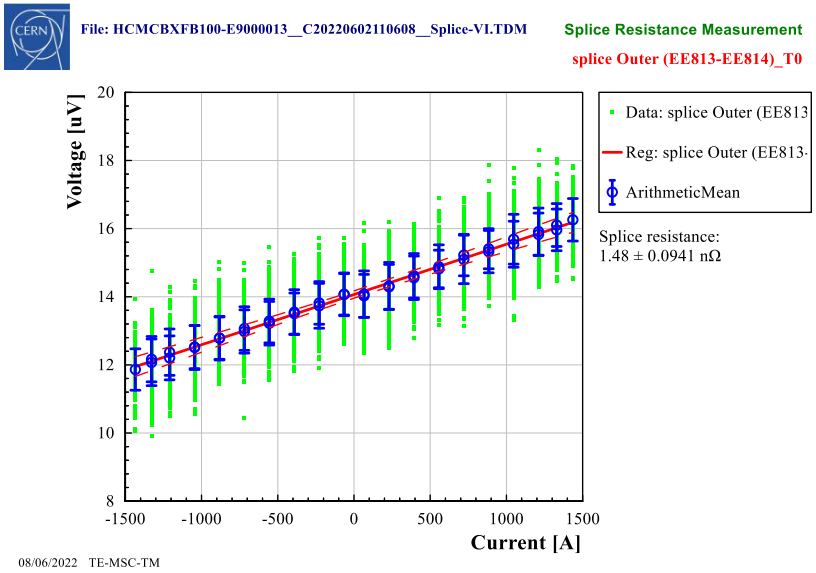


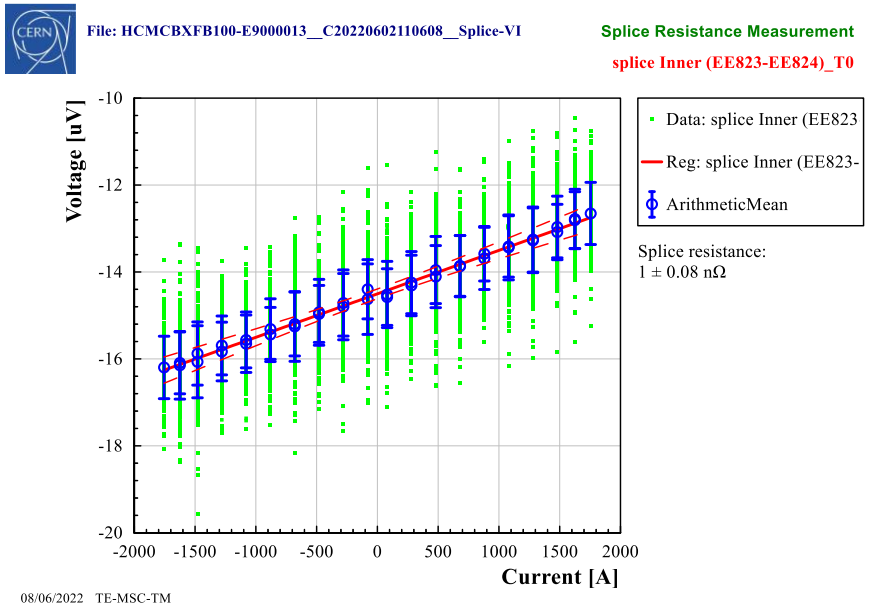


After the thermal cycle no more Quench in any torque direction!

Courtesy of S. Ferradas & G. Willering

MCBXFBP2c splice measurement

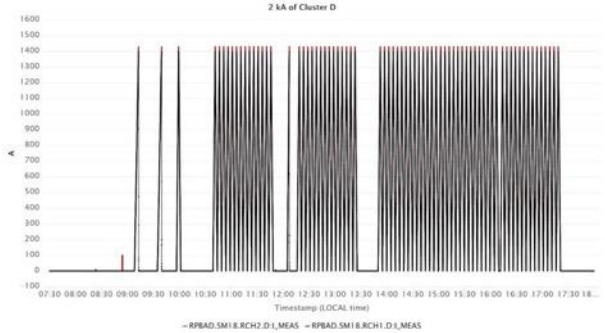




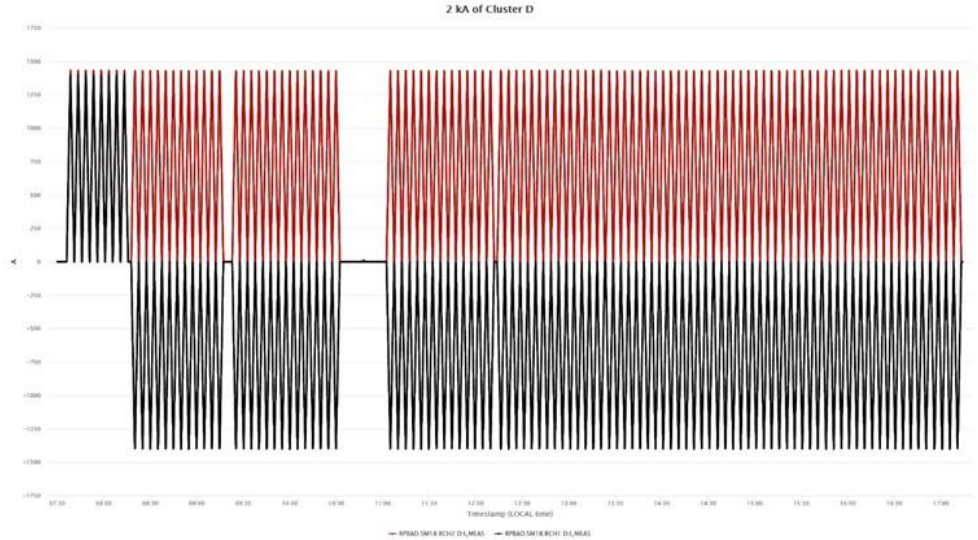
Courtesy of S. Ferradas & G. Willering

MCBXFBP2c endurance test campaign

- An endurance test campaign has been launched
- Around 250 cycles were performed. NO QUENCH
- To be completed with MCBXFB02 first series magnet from ELLYT



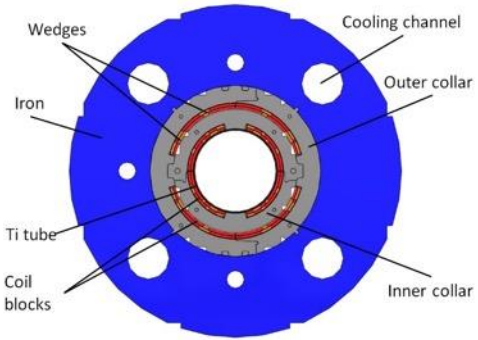
Inner: +1400 A
Outer: + 1430



Courtesy of S. Ferradas & G. Willering

MCBXFBP2c magnetic measurements

Magnetic measurements



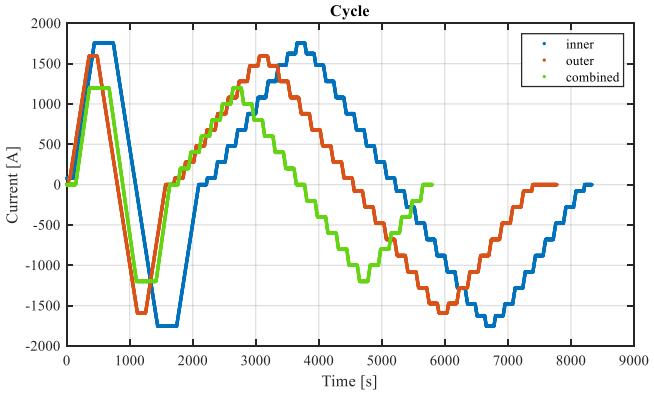
Vertical field from the inner coils:

- main field B_1 (normal)
- first allowed b_3

Horizontal field from the outer coils:

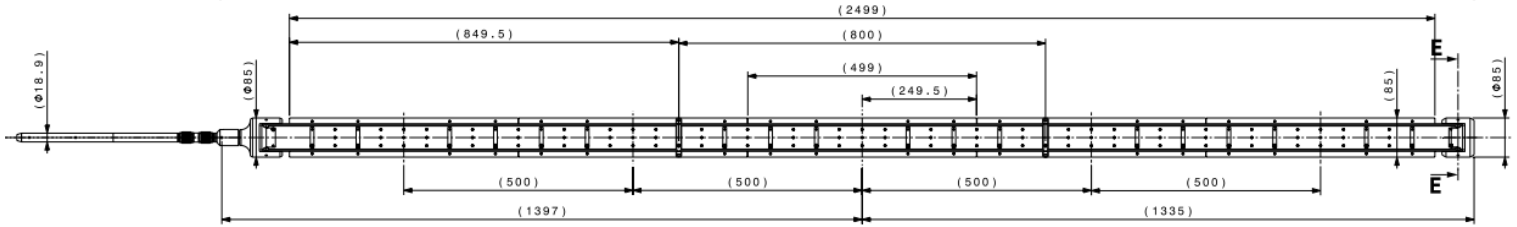
- main field A_1 (skew)
- first allowed a_3

Powering cycles



Rotating-coil in the helium bath of vertical cryostat cluster D in SM18

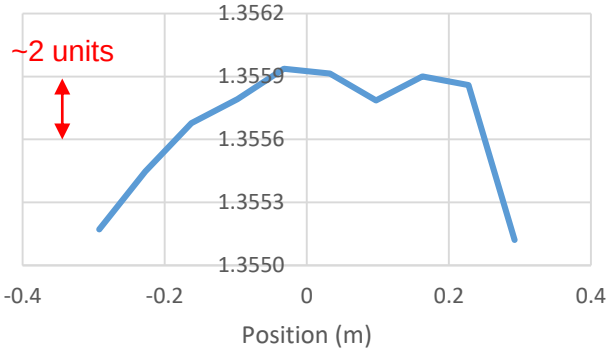
- 5 segments (500 mm each, 2.5 m total)



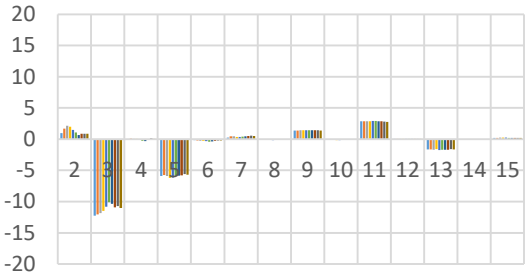
Reference radius 50 mm

MCBXFBP2c Inner Dipole

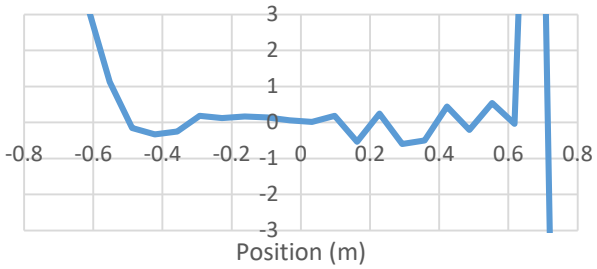
Transfer func. - str section [mT/A]



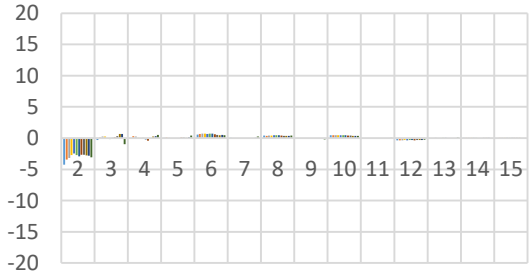
bn [units]



Relative angle [mrad]



an [units]

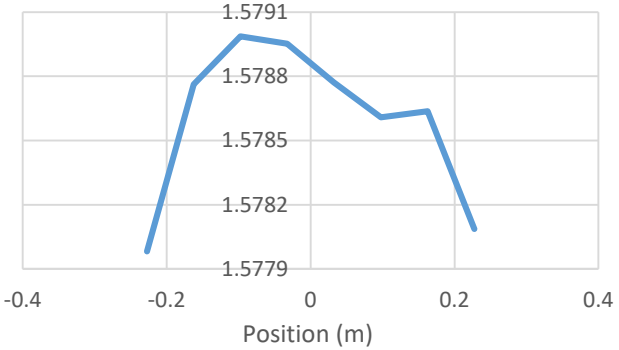


n	Center [units] bn	Center [units] an	Integral [units] bn	Integral [units] an
2	1.27	-2.83	-1.24	-1.42
3	-11.16	0.23	-4.91	0.10
4	-0.04	0.04	-0.51	0.07
5	-5.88	0.03	-5.33	-0.27
6	-0.26	0.63	-0.08	0.15
7	0.44	-0.05	-3.77	-0.02
8	-0.10	0.41	0.15	0.27
9	1.42	-0.04	-0.29	-0.05
10	-0.12	0.43	-0.07	0.33
11	2.86	-0.06	1.65	0.02
12	0.03	-0.33	0.11	-0.43
13	-1.67	-0.01	-1.4	0.03
14	-0.02	0.02	0.01	0.04
15	0.22	0.02	0.13	0.03

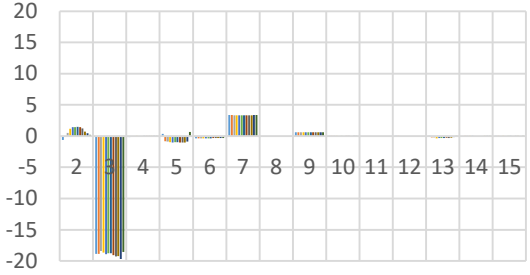
* Measurements at Rref = 50 mm and I=~5A

MCBXFBP2c Outer Dipole

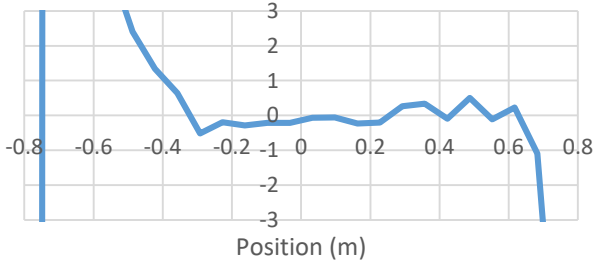
Transfer func. - str section [mT/A]



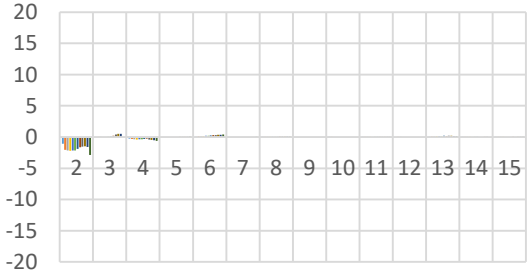
bn [units]



Relative angle [mrad]



an [units]



n	Center [units] bn	Center [units] an	Integral [units] bn	Integral [units] an
2	1.18	-1.92	-0.74	0.21
3	-18.88	0.03	-7.14	1.10
4	0.00	-0.33	0.19	1.02
5	-1.00	-0.03	-0.26	0.49
6	-0.35	0.18	-0.30	0.29
7	3.33	-0.05	2.62	-0.06
8	-0.08	0.05	-0.04	0.03
9	0.61	-0.02	0.43	-0.01
10	0.00	-0.01	-0.02	-0.03
11	-0.05	0.02	-0.06	0.01
12	-0.01	-0.02	0.02	-0.07
13	-0.29	0.13	-0.11	0.30
14	0.00	0.01	-0.02	-0.11
15	0.00	0.00	0.02	0.04

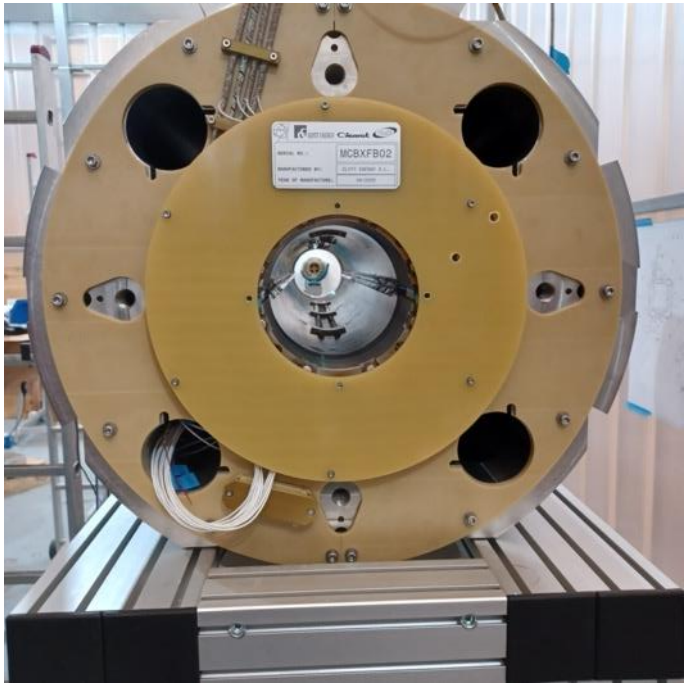
* Measurements at Rref = 50 mm and I=~5A

MM results are reproducible and predictable

Courtesy L. Fiscarelli

Summary

- The fine tuning of the design introduced during the assembly of MCBXFB01 was implemented in MCBXFBP2c by using 2 inner dipole coils produced by ELYTT.
- MCBXFP2c reassembly and powering tests validate the coil fabrication technology transfer to ELYTT.
- This new assembly proves the reproducibility of the results obtained during MCBXFB01 powering tests campaign.
- MCBXFBP2c during powering:
  - Reached nominal +/+ from virgin inner coils in 3 quenches. 2 retraining quenches and last 2 near ultimate current
  - No quenches in the nominal integrated field area
  - Reached ultimate integrated field requirement with only 2 quenches and no quench after TC
  - No quench during the 231 cycles performed for endurance test
  - Perfect memory after TC
- Warm magnetic measurements are close to calculated values.
- Field quality is under control and does not pose significant challenges with present specification
- The first type B magnet of the series fully produced and assembled at Elytt premises will be cold tested at CERN by end of September 2022.
- The powering test at CERN of the first MCBXA prototype is scheduled in December 2022.



Thank you for your attention!

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