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HL-LHC PROJECT

Fabrication and Power Test of last MCBXFB Magnets

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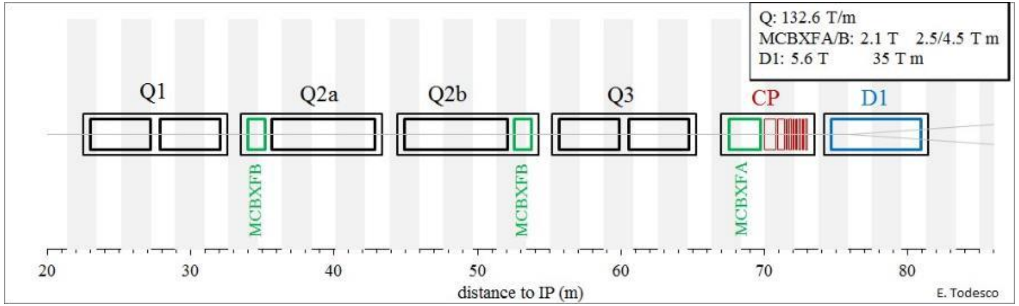
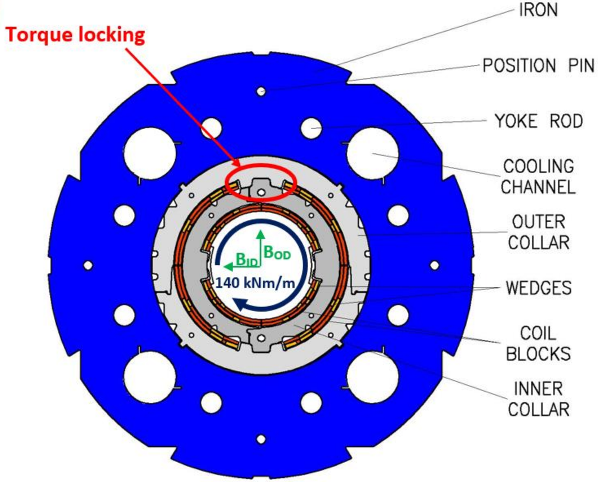
Introduction. MCBXF Magnets



MCBXF Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	4.5 (A) / 2.5 (B) Tm
Minimum free aperture	150 mm
Nominal current	< 2000 A
Radiation resistance	35 MGy
Physical length	< 2.5 (A) / 1.505 (B) m
Working temperature	1.9 K
Iron geometry	D1 (A) / MQXF (B) iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)



- MCBXF are nested dipole H/V correctors, the last ones before the interaction point (experiments)
  - 150 mm single aperture
  - Two lengths with the same cross section:
    - A-Type (2.5 m long): 1 prototype + 4 series + 2 spares
    - B-Type (1.5 m long): 2 prototypes + 8 series + 4 spares
- The nested collaring assembly, never used before, holds the torque between both dipoles in combined powering: up to **140 kNm/m** in prototypes, **147kNm/m** for the series (explained later)

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Second Short Prototype reassembly (P2b)

- Short MCBXF Magnets produced at CIEMAT (assembly and test at CERN): P1 – P2a – P2b – B01

- First short prototype (P1):
  - Reached nominal in combined operation after filling an existing gap in the midplane at the coil ends.
  - Retraining needed after each torque inversion.

- First assembly of the second short prototype (P2a):
  - Uniform preload along the midplane of the coils.
  - In combined operation performance very similar to P1, with slightly lower limits.

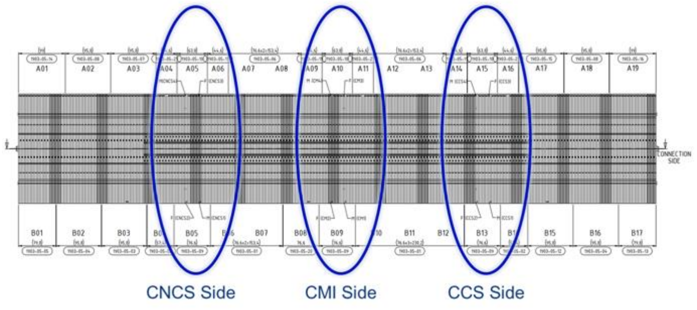
- In P2b a **100 micron shim** was added in the inner dipole to **increase preload by 20 MPa**, in order to:
  - Increase friction between coils and collars at coil ends, avoiding them to slide in combined operation.
  - Reduce the chance of losing contact between collar noses and coils in the window pole at nominal torque.

Second Short Prototype reassembly (P2b)

- Best solution to optimize *b3* (at cold and at nominal current) is to split additional shim in two, **50 micron next to the pole turn and 50 micron at the midplane**:

(*units*)	P2a	Computed	Expected
b3	-6.9	-9.0	-9.4
b5	-7.5	-1.6	-8.25

- Pressure controlled with strain gauges during collaring at the press, important to preserve coils integrity. **Maximum average pressure** expected in P2b of **-202 MPa.**

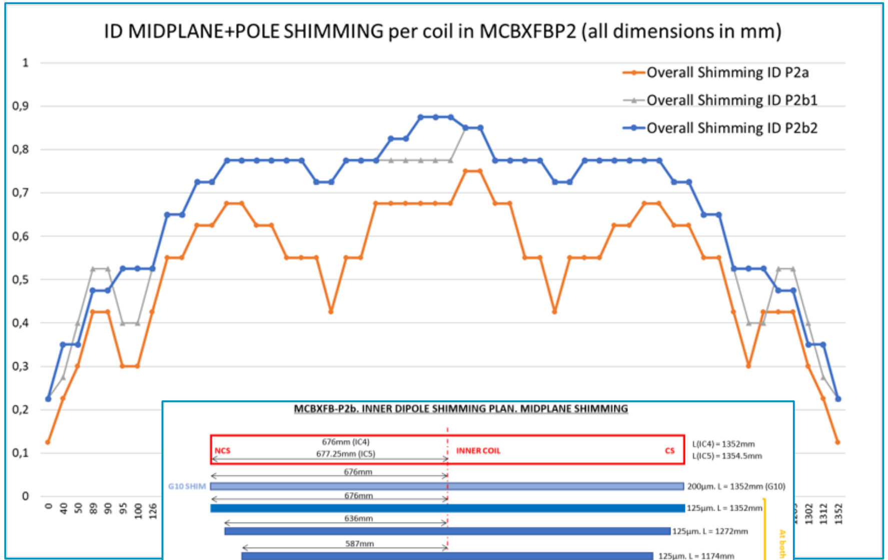


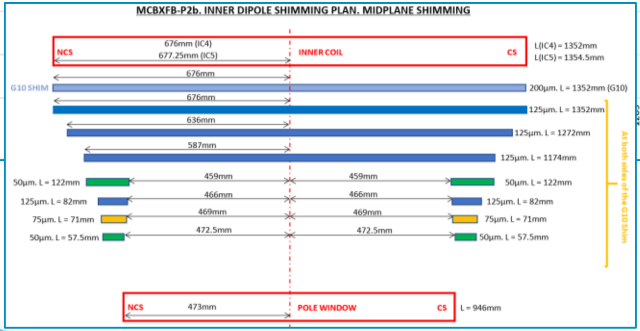
Collars Location

Courtesy J.C.Perez (CERN)

Second Short Prototype reassembly (P2b)

- **HHS FujiFilm Prescale paper**, sensitive up to 300 MPa, used to check the pressure at the coil ends. It showed step transitions at the coil ends:





- In a second step the shimming transitions were smoothed and also a **100 micron shim** added **at NCS pole turn** (P2b2)

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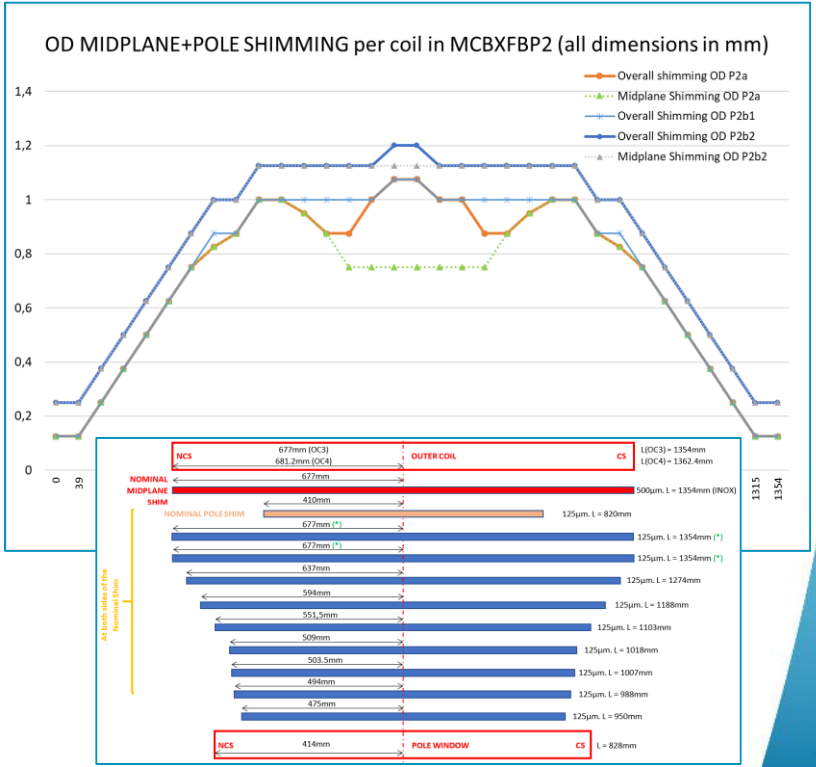
Second Short Prototype reassembly (P2b)

- Long midplane shims ends are 45º inclined respect the coil axis, and symmetric shims are cut in the opposite orientation => **more progressive shimming**



- For the Outer Dipole (OD), **two shims at the pole turn were shifted to the midplane** to target nominal ***a3*** (P2b1), and a **125 micron shim** was added to **increase the preload in 20 MPa** (P2b2).

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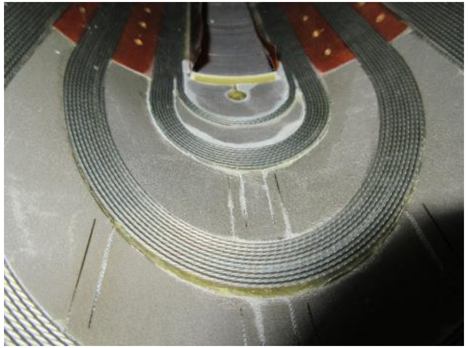
Retraining of the Second Short Prototype (P2b)

- Instrumented collars in ID were kept during the powering tests at cold. The **preload at cold was -43 MPa**, very similar to the preload in P1, -37 MPa.
- Performance of P2b very similar to P2a:
  - Reached ultimate current in both circuits without quenches, standalone.
  - Most of the quenches on ID coil heads.
  - Quench free region: 32% of nominal torque (35% in P2a).
  - P2b becomes unstable at currents above 90% of nominal current (de-training).
  - 90% of P2b quenches in coil IC5.
- Visual inspection showed an increasing number of fracture lines in the coil resin, appearing close to the pole at the first endspacers. As the maximum torque reached increases, the fracture lines spread to almost every endspacer-cable interface.



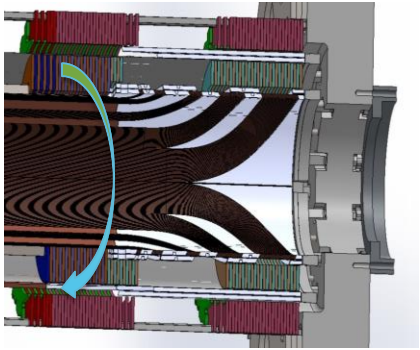
P1 after first power test (50% nominal torque)

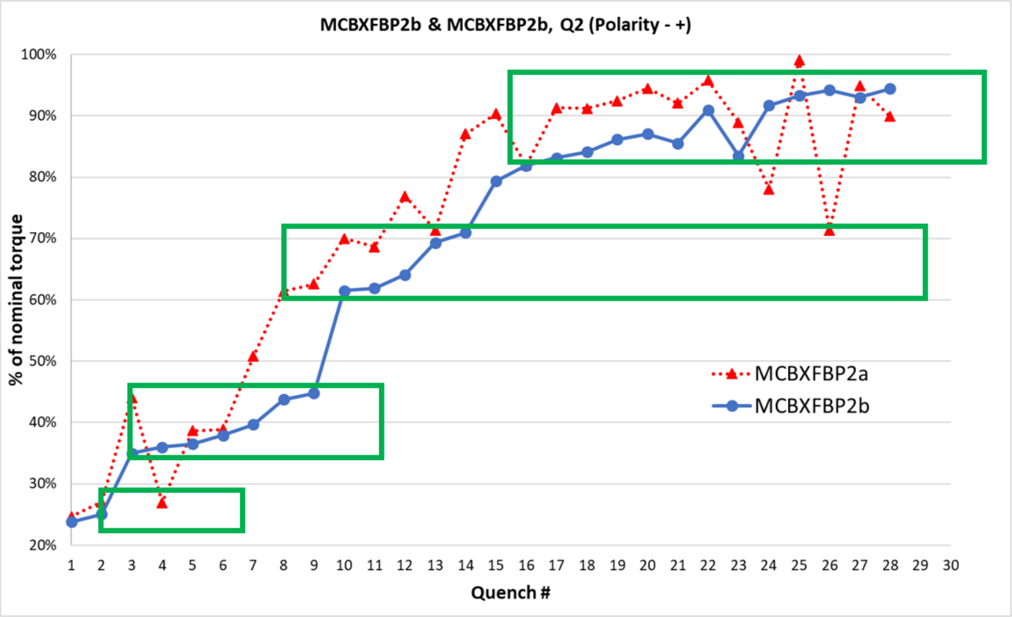
P1 after fourth power test (104% nominal torque)

Retraining of the Second Short Prototype (P2b)

As training is not sensitive to **axial preload**, we can assume that:

- Coils do not slide w.r.t. the collars
- Coil ends do not slide w.r.t. the endplates.



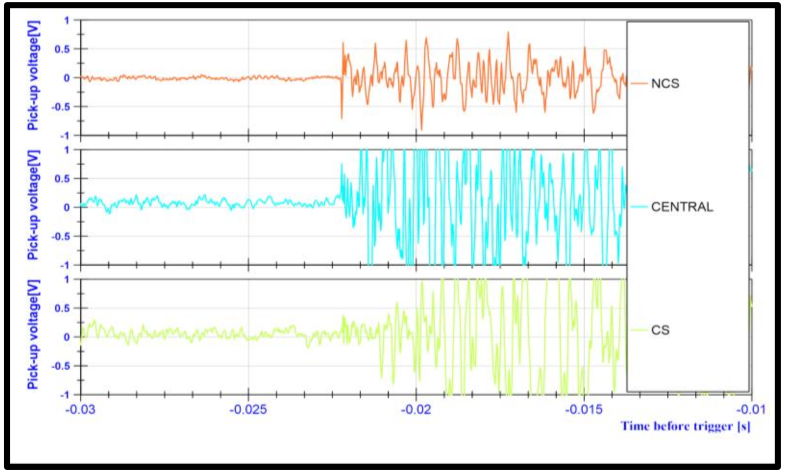


- **Shear stress** between the cable blocks, wedges and endspacers, could explain the fracture lines and the step-wise training curve

Quench antenna measurements (P2b)

- Magnetic measurement shaft used as quench antenna (five 500 mm long segments). Segment 3 centered with the magnet. Segments 2, 3 & 4 used to locate quenches.

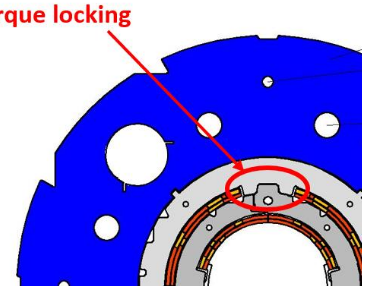
- As the current increases, the signal measured at the central segment approaches in time to the onset of the segment corresponding to the triggering coil end => Quenches at coil ends had their origin, quite likely, **close to the straight section**.

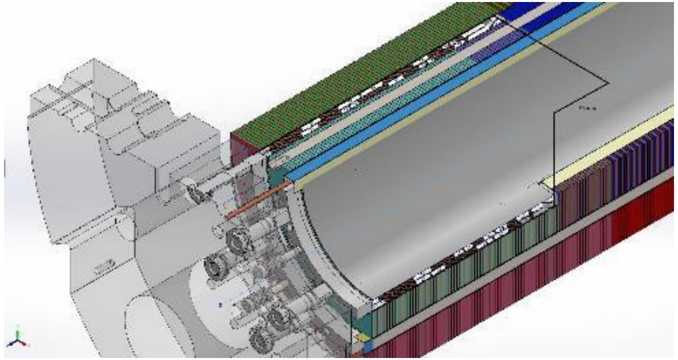


Courtesy S.Ferradas (CERN)

Fine tuning of the first series magnet (B01)

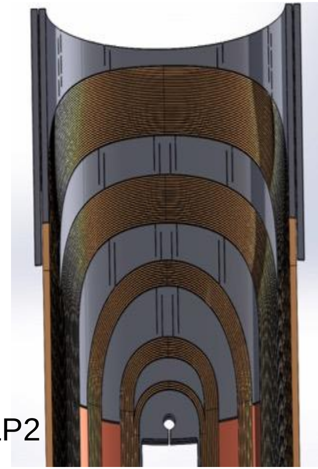
Torque locking is only possible at the OD pole window (828 mm long). ID pole window is 946 mm long => 59 mm at each side **without torque locking**.





A fine tuning was implemented in B01:

- Inner coil length was **shortened by 118 mm** in order to **reduce the cantilever length** of coil ends (59 mm less at each coil extremity).
- Endspacers with **longer legs** to **increase the rigidity** at the beginning of the coil heads.



P1&P2

B01

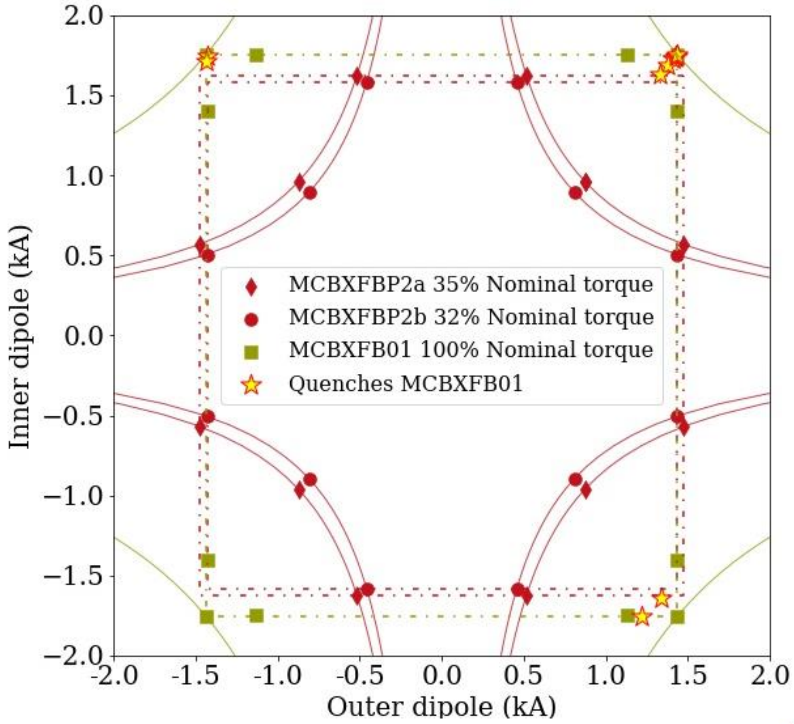
Powering Tests of the first series magnet (B01)

No instrumented collars during the powering tests:

- Reached ultimate in both circuits standalone.
- Reached nominal in Q1 and Q2 no matter the powering sequence. **Without re-training**.
  - 6 quenches (over 87%) to reach nominal in all quadrants (85 in P2a)

After the thermal cycle:

- **Good memory.**
- **Excellent performance**, reaching ultimate current during combined powering.



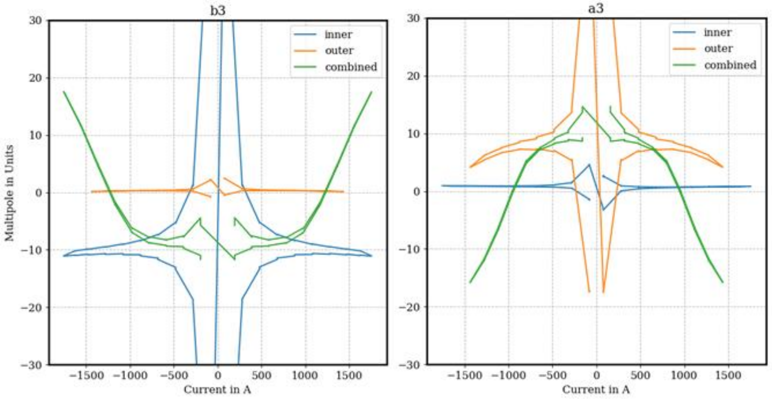
Courtesy S.Ferradas (CERN)

Powering Tests of the first series magnet (B01)

- As the ID is shorter in B01 the nominal & ultimate values for current and field in both dipoles had to be increased.

B01	Inner Dipole	Outer Dipole
Nominal current	1755 A	1435 A
Ultimate current	1885 A	1545 A

- Measured integral fields: 2.57 Tm for standalone ID and 2.56 Tm for standalone OD. In combined powering 2.48 Tm for ID, and 2.50 Tm for OD.
- All multipoles within specifications: *b3* and *a3* below 20 units, the rest below 5 units.



	ID 1755 A OD 0 A		ID 0 A OD 1435 A		ID 1755 A OD 1435 A	
	MEAS.	COMP.	MEAS.	COMP.	MEAS.	COMP.
b3	-10.85	-11.08	-0.61	0	12.05	17.41
b5	-6.74	-1.51	-0.10	0	-3.19	0.18
b7	-3.55	-2.24	1.01	0	-3.58	-2.57
b9	0.15	0.7	0.14	0	-0.12	0.71
a3	-1.95	0	3.81	3.22	-12.65	-11.56
a5	-1.79	0	0.76	1.64	2.70	3.12
a7	-1.19	0	-2.45	-2.83	-0.86	-2.84
a9	-0.26	0	-0.28	0.54	-0.06	0.58

Conclusions

- MCBXF are the first nested superconducting accelerator magnets with **mechanical torque locking** (up to **147kNm/m** in B01).

- Reassembly of the second prototype (P2b):
  - Performance very similar to P2a
  - **Increasing the preload** does not improve the performance of the magnet
  - The **quench free region** is below **32%** of the nominal torque, slightly lower than in P2a (35%).

- Thanks to the **fine tuning** in the design of the magnet, B01 has **an excellent performance**:
  - Quench-free region improved to **100%** of nominal torque.
  - Virgin **training reduced** from 30 to 3 quenches.
  - Reached **ultimate** current during combined powering.
  - The measured values of the field quality and the transfer functions are **within magnet specifications**.

Thanks for your attention

ACKNOWLEDGMENT

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