Technical Meeting on MQXFB08 : Assembly and Pre-load target

Susana Izquierdo Bermudez, Penelope Quassolo on behalf of MQXF team

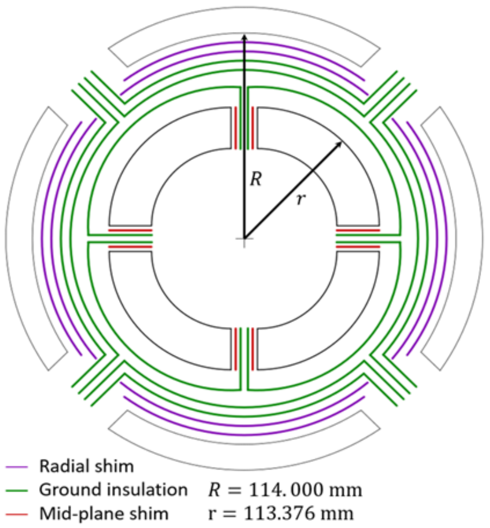
03/12/2024

Technical Meeting MQXFB08 Assembly (December 3, 2024) · Indico

Shimming plan

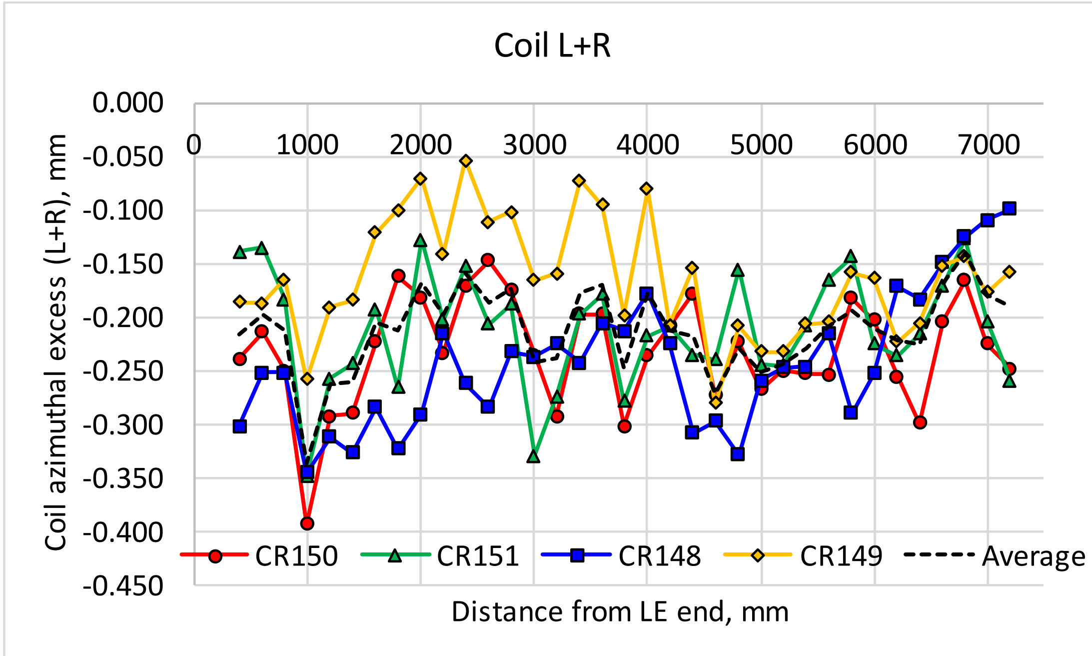
Shimming strategy - Mid-plane and radial shims

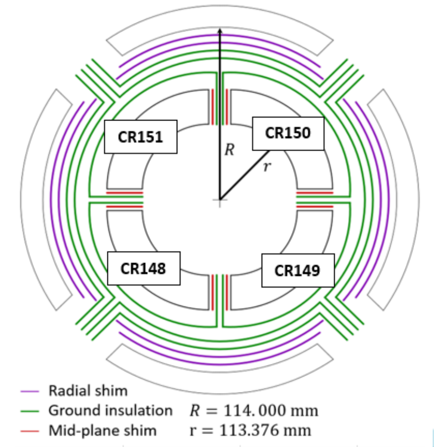
- **Strategy:** coils with different azimuthal sizes are shimmed to match the largest one. If all coils are smaller than nominal size, they are shimmed to match the latter value. Shimming is placed on the mid-plane.
- The resulting variation of outer radius is compensated by adding/removing radial shims*.
- 0.125 mm of radial shims are removed systematically to improve contact on the mid-plane between collar and coil → experience from LARP and MQXF short models
  - So-called "LQ effect"



*The ground insulation layers must be respected. Targeting as a baseline to remove at least one of the radial shims, coil average size is exceeded when $L+R_{average}$ > 200 µm. Non-optimal contact with the collars.

MQXFB08: Coil Size



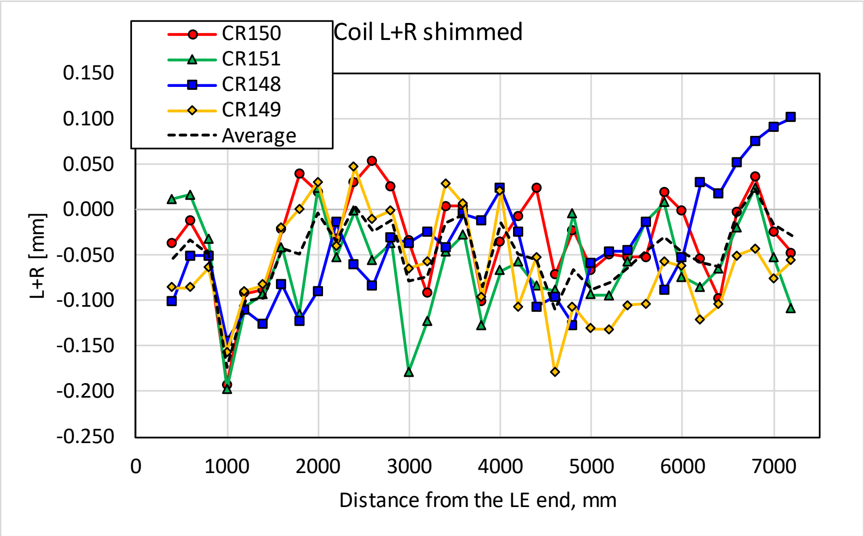


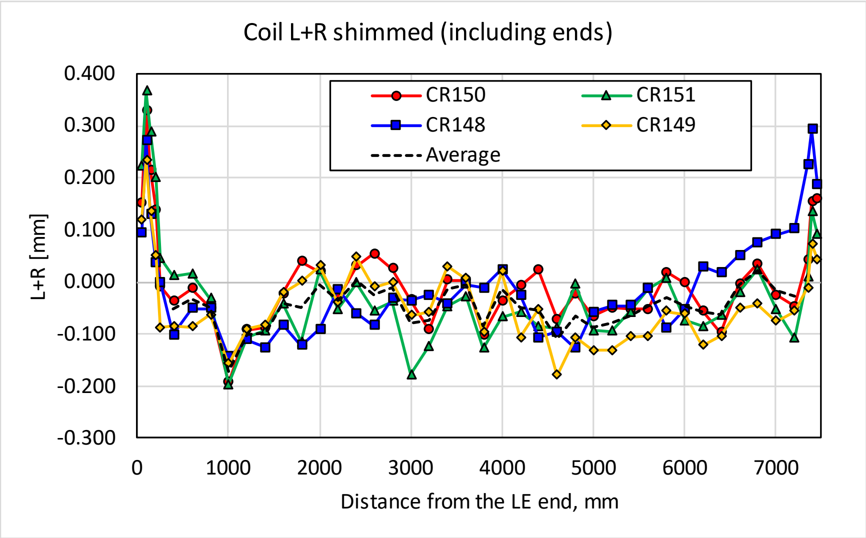
		Average (Excluding ends)	Rounded value
Azimuthal excess L+R [µm]	CR150	-231	-200
	CR151	-211	-150
	CR148	-242	-200
	CR149	-163	-100

	Shim
CR150	200
CR151	150
CR148	200
CR149	100

MQXFB08 largest coil (CR149) is smaller than the nominal azimuthal size, so all the coils are shimmed to the nominal azimuthal size. CR148 is the smallest.

MQXFB08

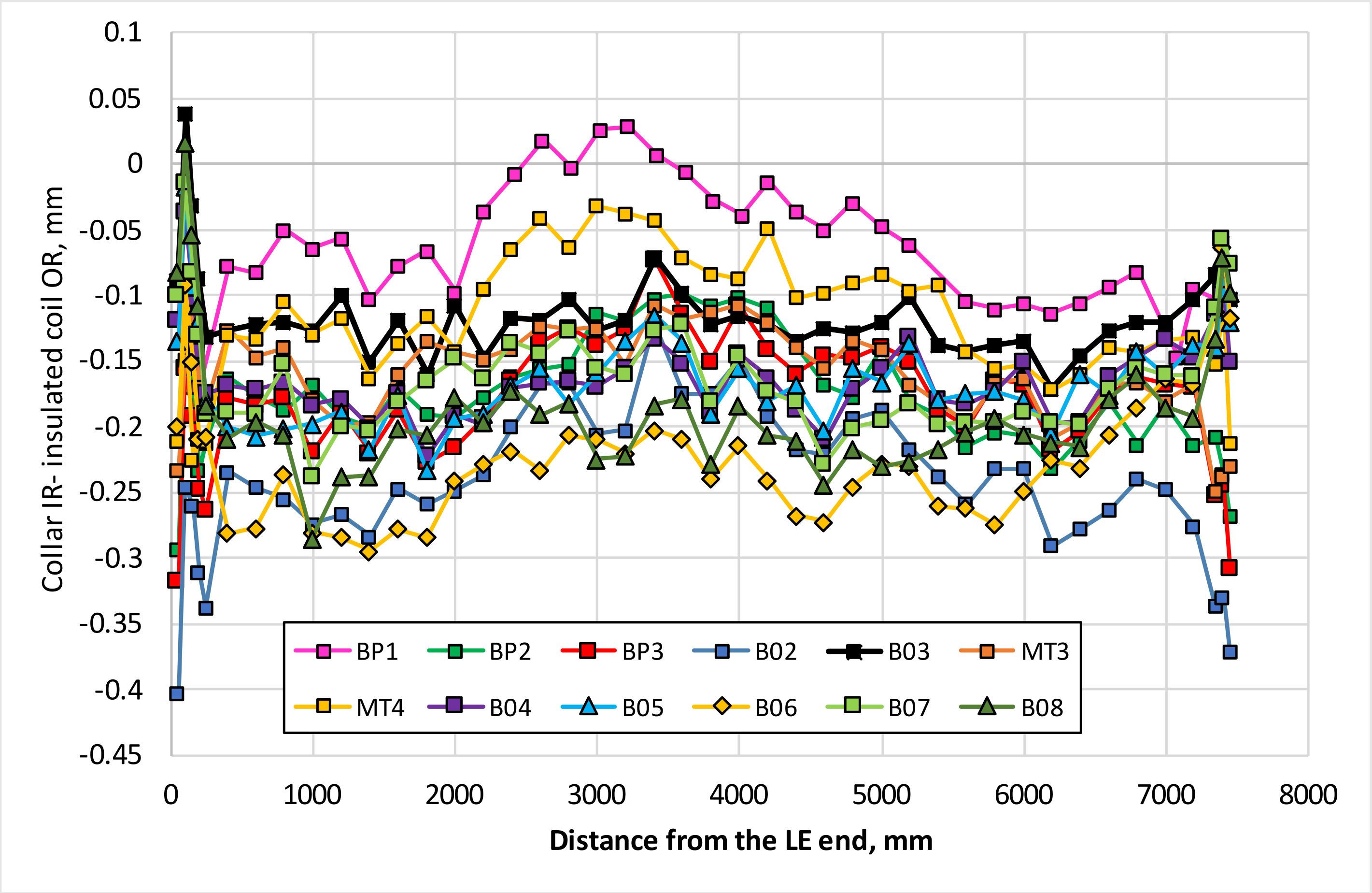

Coil L+R shimmed
CR150
CR151
CR148
CR149
Average
L+R [mm]
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
0
1000
2000
3000
4000
5000
6000
7000
Distance from the LE end, mm


Coil L+R shimmed (including ends)
CR150
CR151
CR148
CR149
Average
L+R [mm]
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
0
1000
2000
3000
4000
5000
6000
7000
Distance from the LE end, mm

MQXFB08 -175 um shimming plan

Radial size and comparison to previous magnets

The radial shim is defined in order to have a coil pack dimensions slightly smaller* to B04/B05/B07 but bigger than B06. The ends have a similar size to previous magnets.



The keys kits are slightly bigger than nominal. To have an easier insertion (difficult in B07) of the last keys, B08 coil pack will be a bit smaller

MQXFB08 -175 um shimming plan

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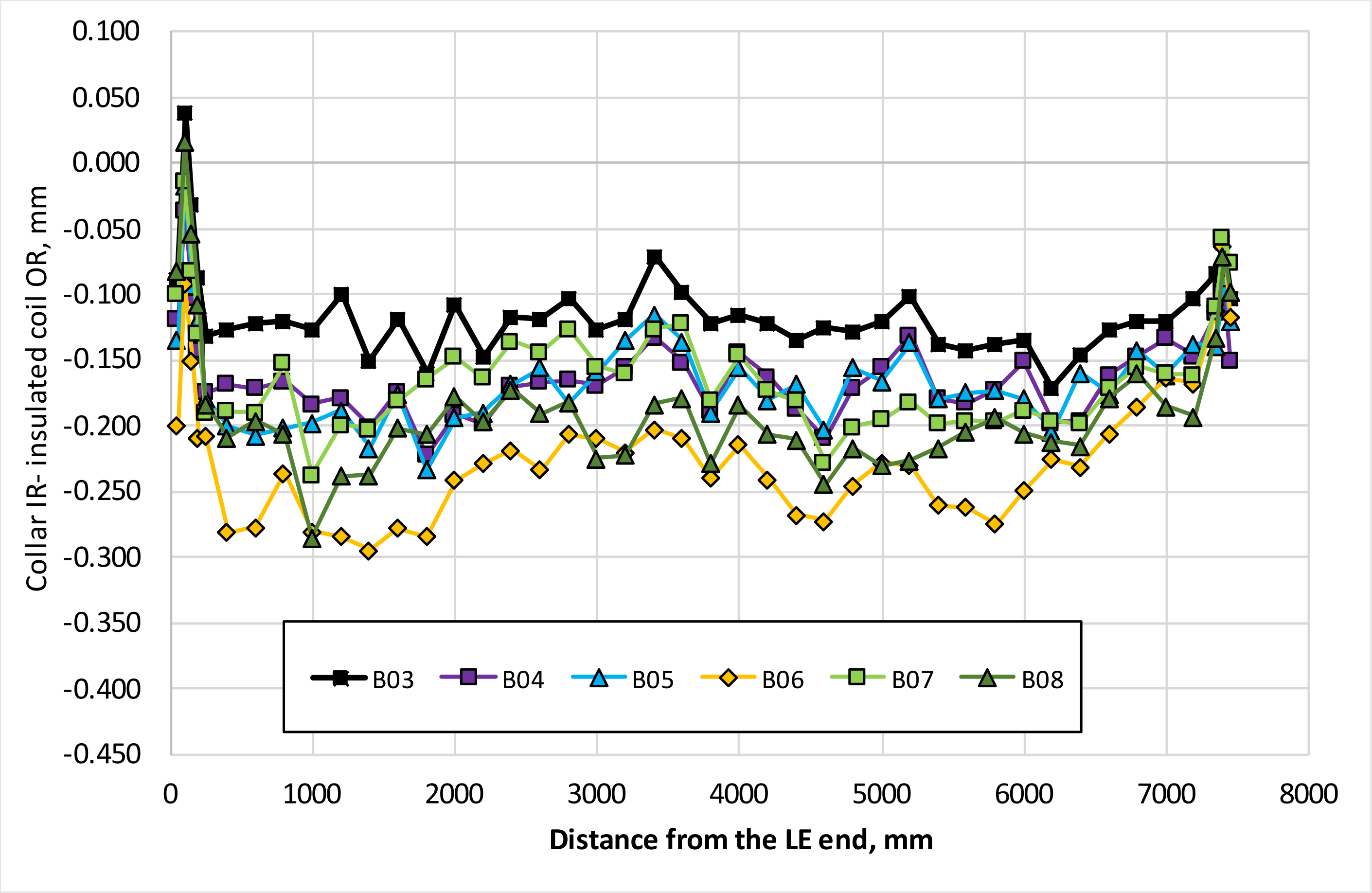
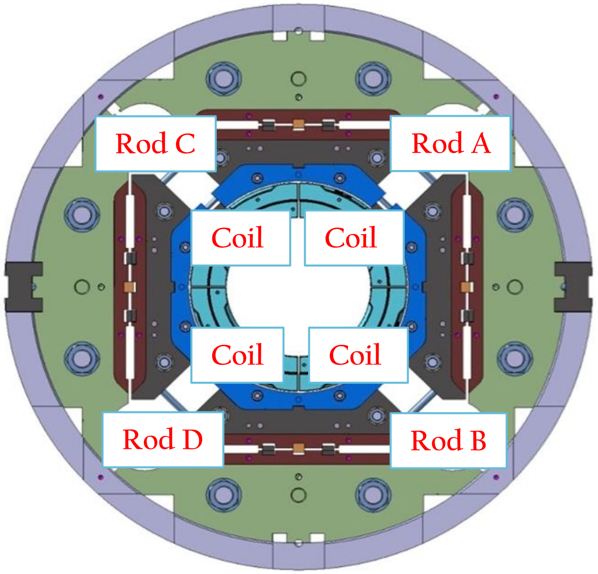


The keys kits are slightly bigger than nominal. To have an easier insertion (difficult in B07) of the last keys, B08 coil pack will be a bit smaller

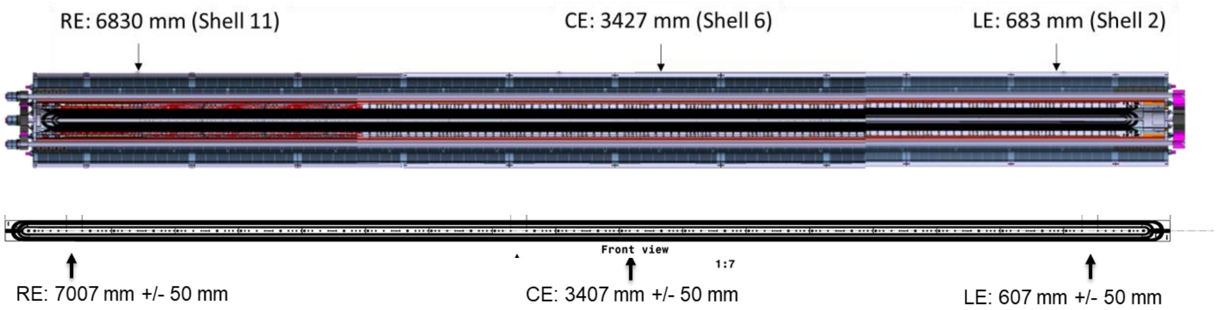
Pre-load targets

Instrumentation overview

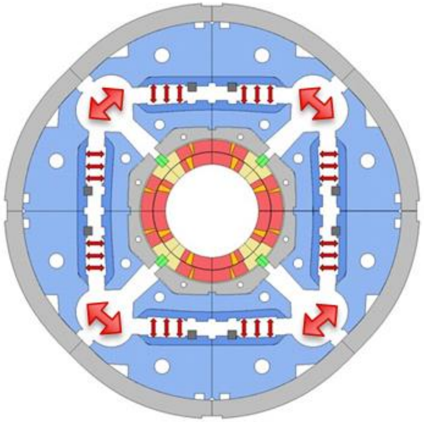
Magnet component	Number & Directions	Bridge configuration	Type
SHELL	12 (Θ) 12 (Z)	SG quarter bridge + thermal compensator	Cr – Ni / Polyimide HBM LC11-6/350
COILS	12 (Z) 12 (Θ)	FBG (+ temperature sensor to compensate T effect)	FemtoSecond® 4 arrays with 2 FBG



- Coil and shell are instrumented in three axial locations (LE (lead), CE (center), RE (Return))



Azimuthal pre-load target (from B03 on)



- The allowable peak stress in the coil during loading is -110 MPa, achievable thanks to the new loading procedure with auxiliary bladders (AUP has -135 MPa as maximum allowable stress).

- The target room temperature preload from MQXFB03 is:
  - Average shell stress: 58 ± 6 MPa;
  - Average pole coil stress: -80 ± 10 MPa
  - Rod strain: 650 με
  - This is a target not a requirement, and in case the maximum allowable peak stress in the conductor (110 MPa) is reached, the average pre-load will be lowered accordingly to fulfill the peak stress requirement

- With the new welding procedure (applied from MQXFBP3), we expect no increase on the azimuthal stress of the coils during welding

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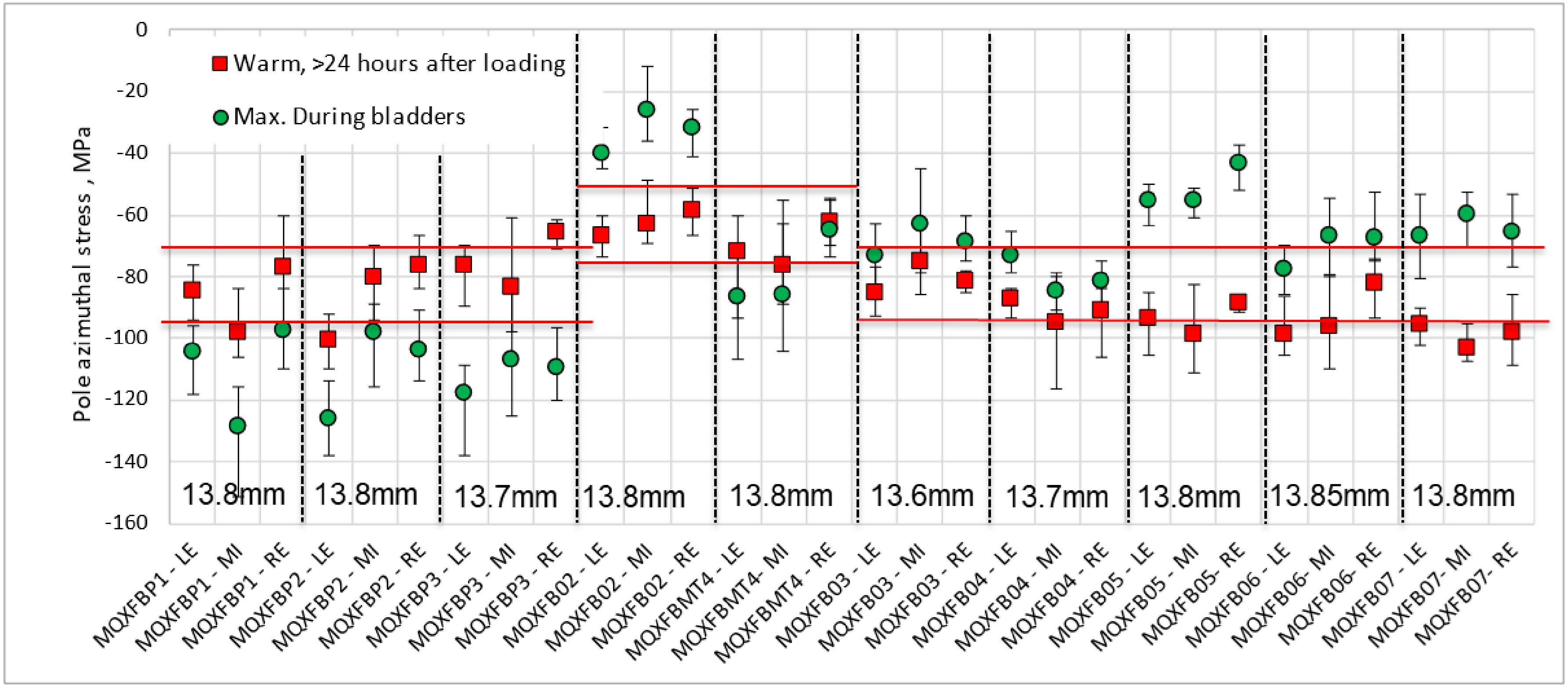
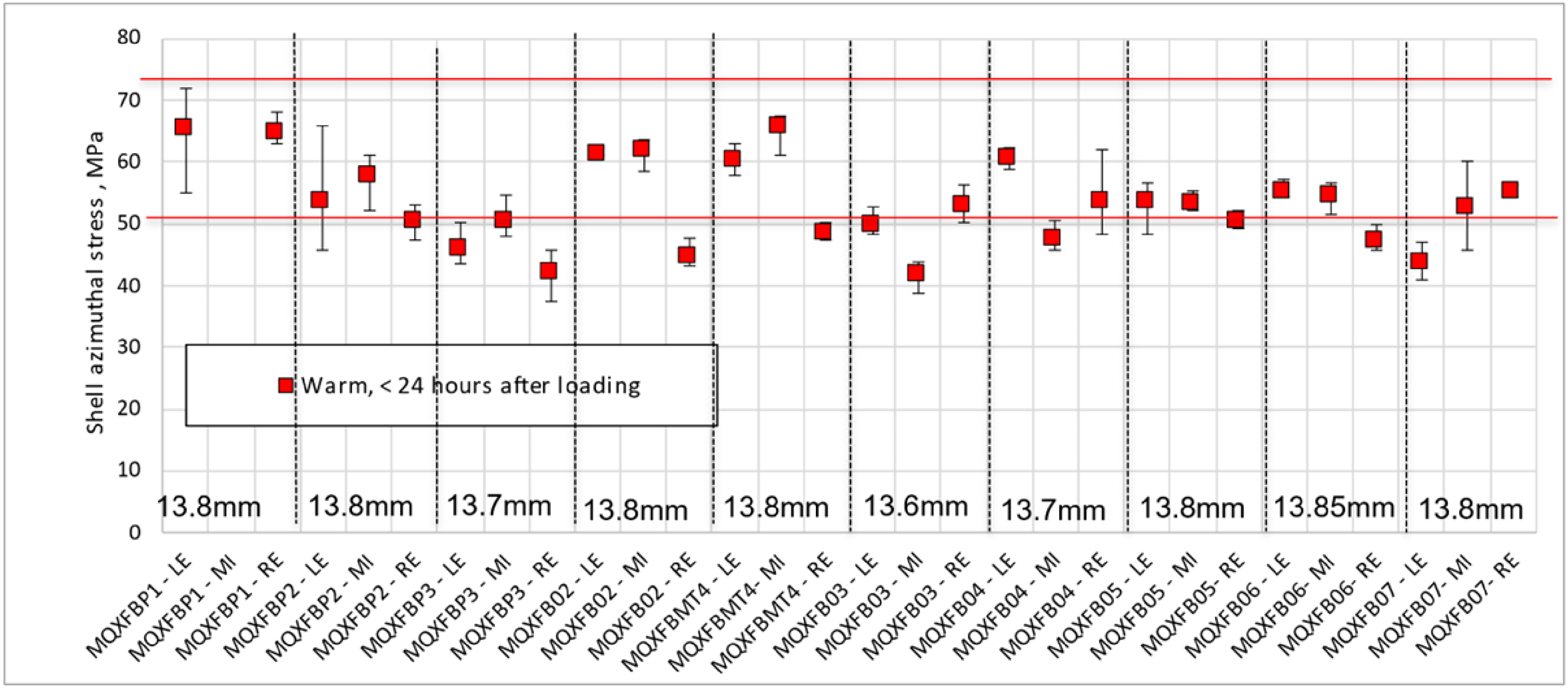
RT: Targets vs achieved



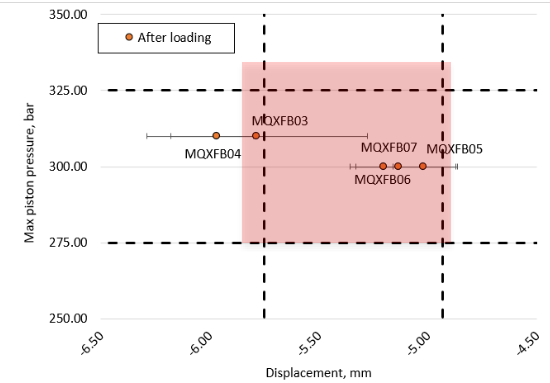
RT: Targets vs achieved

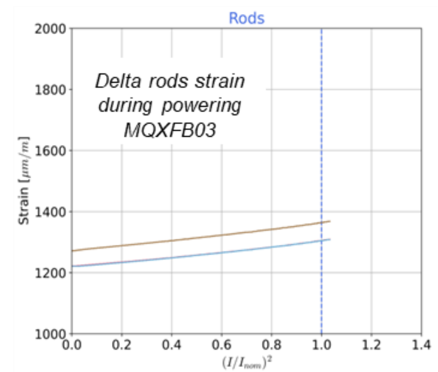


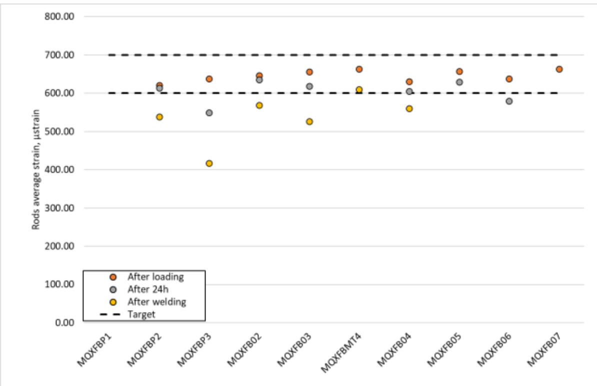
Axial pre-load

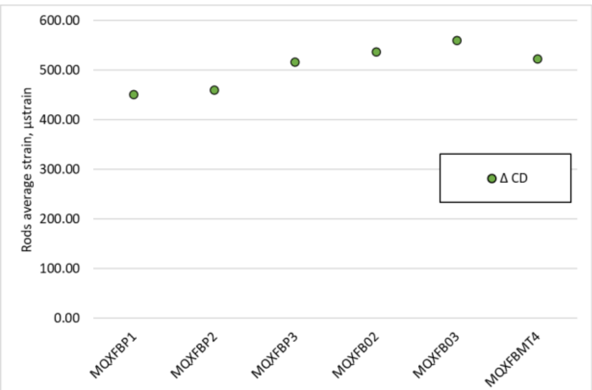
- Small change of strain on the rods during powering → longitudinal stiffness of the structure is as expected, and overall behaviour is like what we have seen in MQXFS and MQXFA
- From BP2, all magnets loaded so far with the same axial pre-load (at RT), 650 ± 50 µstrain **after loading.**
- The equivalent targets for pressure and displacement to guarantee the same axial pre-load are:
  - Pressure target: **300 ± 25 bar**
  - Displacement target: **-5.33 ± 0.4 mm**

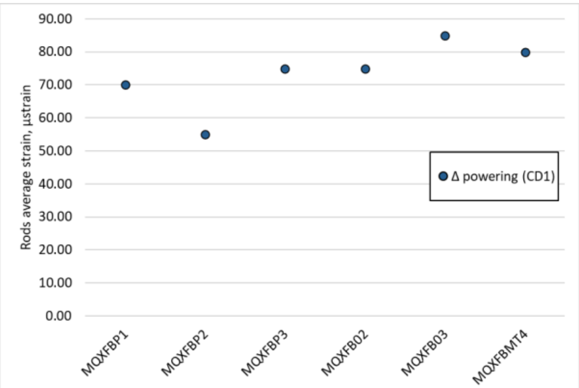
  This was proved with B05 and B07, where the displacement instrumentation was correctly place. **From MQXFB08 we will not have rods instrumentation.**
- **During cooldown** the delta strain is in between 450 µstrain and 550 µstrain for all the magnet
- **During powering** the delta strain is in between 75 µstrain and 85 µstrain from magnet BP3.
- MQXFB03 (last magnet with instrumentation at cold) has similar behaviour to the previous magnets, although now the magnet is mostly quenching in the ends





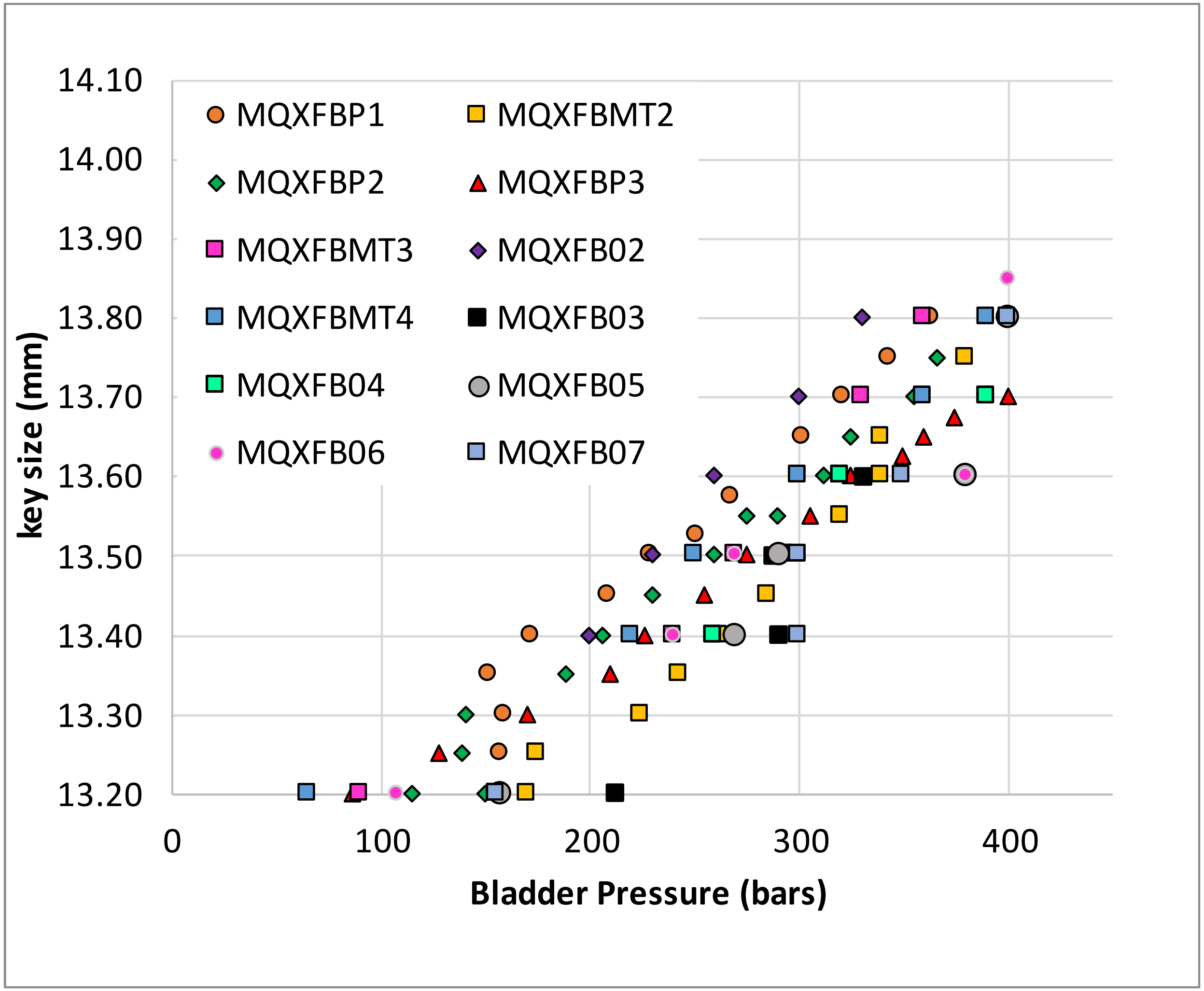






Bladder pressure

- The other observable we have during assembly is the bladder pressure
  - Assembly tolerances play a role, on some occasions, you need 20-30 bars to overcome a singularity in the structure
  - Requirement: never exceed 400 bars



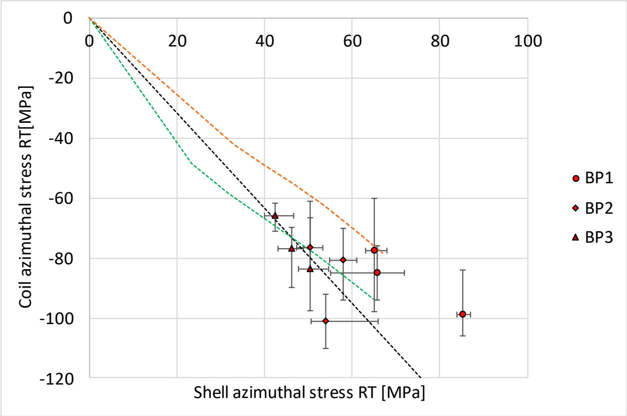
RT transfer function

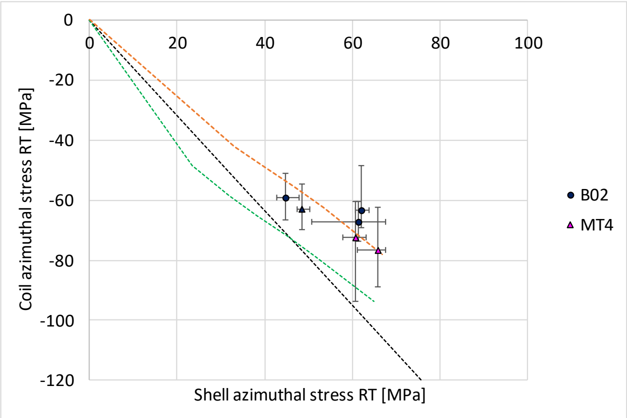
So far, relatively good agreement between expected transfer function and measured transfer function

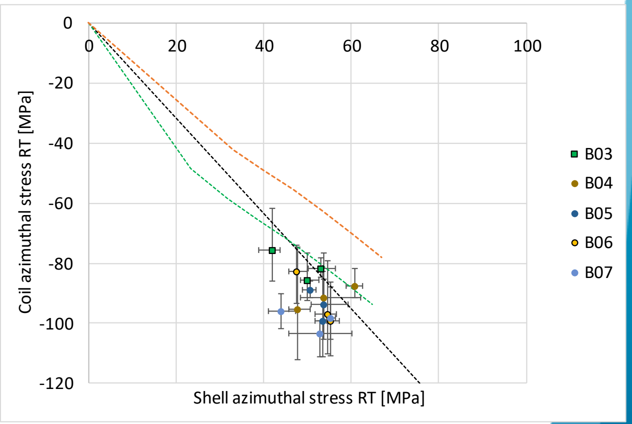
- In B02/MT4 we show the change of slope due to the new loading procedure (orange dashed line)
- From B03 we are closer to the original slope (black dashed line) due to the 'new coil geometry' (green dashed line)
- Looking at the averages stress after loading (table), they are rather unifirom, but there is a spread of +-20 MPa in the coil, +- 10 MPa in the shell

Delta = Stress loading – Stress centering

	Shell avg. [Mpa]	Delta* shell [Mpa]	Coil avg. [Mpa]	Delta* coil [Mpa]
B07	51	44	-99	-87
B06	53	46	-91	-87
B05	55	49	-92	-88
B04	55	38	-91	-76



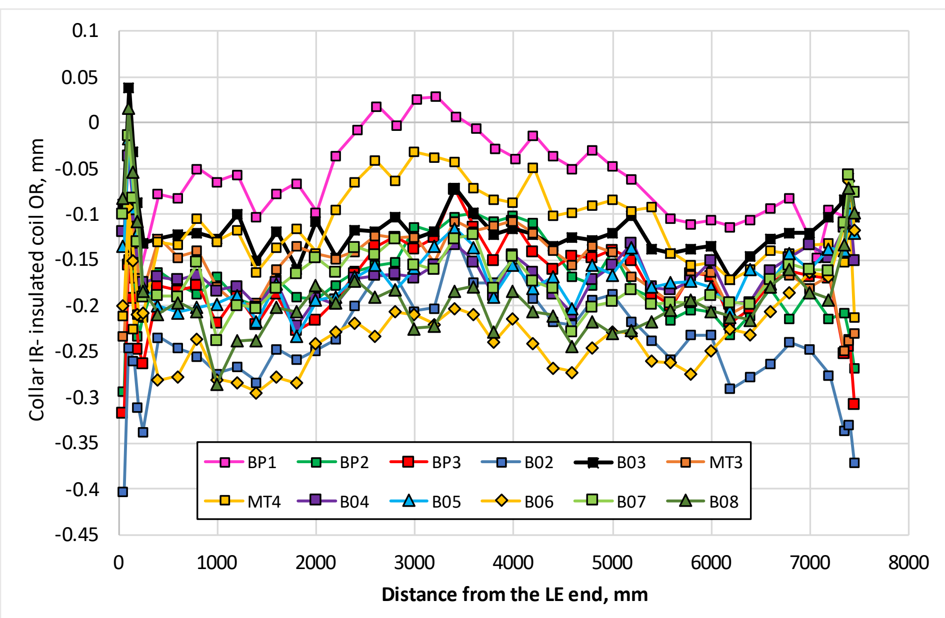


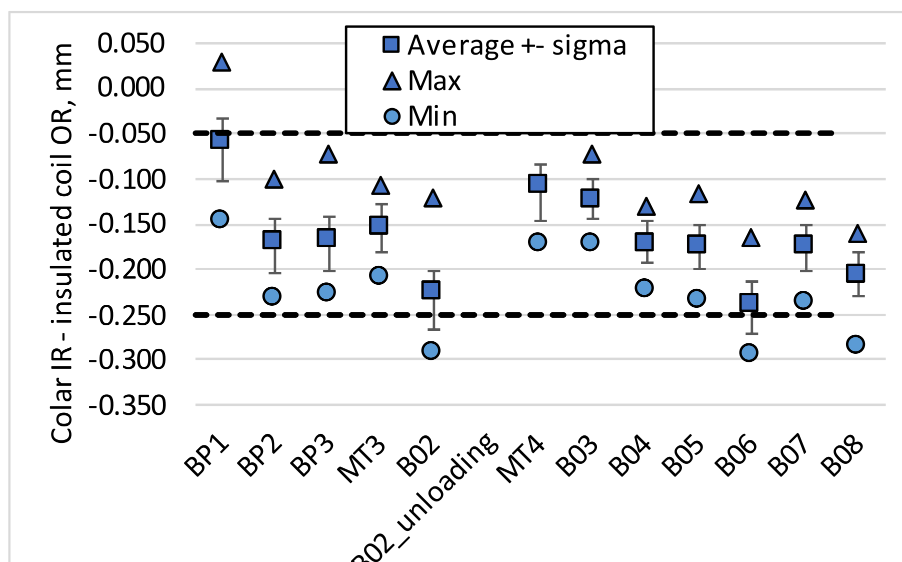


Loading key target

- The target is to have a key 13.8 mm
  - At CERN we don't have finer granularity

	Coil pack radial size deviation							Loading key thikness	Coil pack radial size deviation + loading key thikness -13.8					
	RE	MI	LE	AVE SS	MAX SS	MIN SS	STD SS		RE	MI	LE	AVE SS	MAX SS	MIN SS
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
BP1	-0.049	0.008	-0.082	-0.058	0.029	-0.147	0.045	13.800	-0.049	0.008	-0.082	-0.058	0.029	-0.147
BP2	-0.177	-0.102	-0.185	-0.168	-0.099	-0.232	0.037	13.800	-0.177	-0.102	-0.185	-0.168	-0.099	-0.232
BP3	-0.167	-0.074	-0.183	-0.166	-0.072	-0.227	0.035	13.700	-0.267	-0.174	-0.283	-0.266	-0.172	-0.327
B02	-0.249	-0.123	-0.246	-0.225	-0.121	-0.291	0.041	13.800	-0.249	-0.123	-0.246	-0.225	-0.121	-0.291
MT4	-0.133	-0.043	-0.132	-0.107	-0.031	-0.171	0.039	13.800	-0.133	-0.043	-0.132	-0.107	-0.031	-0.171
B03	-0.119	-0.072	-0.131	-0.124	-0.072	-0.172	0.019	13.600	-0.319	-0.272	-0.331	-0.324	-0.272	-0.372
B04	-0.134	-0.133	-0.171	-0.171	-0.131	-0.222	0.022	13.700	-0.234	-0.233	-0.271	-0.271	-0.231	-0.322
B05	-0.160	-0.116	-0.207	-0.174	-0.115	-0.233	0.026	13.800	-0.160	-0.116	-0.207	-0.174	-0.115	-0.233
B06	-0.164	-0.203	-0.276	-0.239	-0.164	-0.294	0.033	13.850	-0.114	-0.153	-0.226	-0.189	-0.114	-0.244
B07	-0.160	-0.126	-0.189	-0.174	-0.123	-0.238	0.027	13.800	-0.160	-0.126	-0.189	-0.174	-0.123	-0.238
B08	-0.185	-0.184	-0.197	-0.206	-0.160	-0.285	0.024	13.800	-0.185	-0.184	-0.197	-0.206	-0.160	-0.285

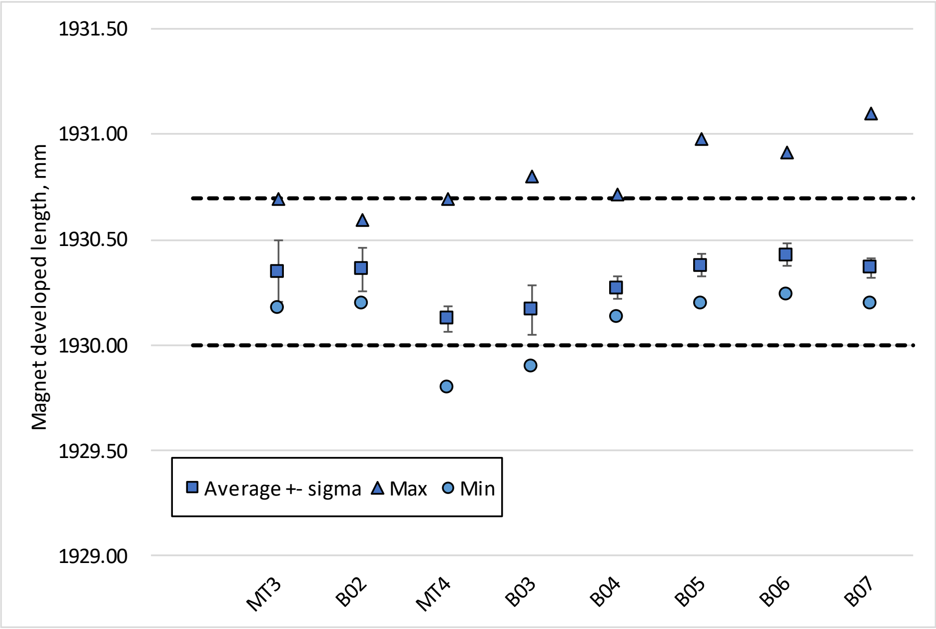




'Straight section' only, i.e., from 400 mm to 7200 mm

Magnet outer developed length

- **In the middle of the aluminium shells, the developed length after loading shall be 1930.2 mm +0.5/-0.2 mm**
  - For a pole pre-stress of 80 MPa, the expected increase of circumference is 1.2 mm in the middle of the aluminium shells, 1.6 mm in the extremities
  - Remark: these measurements are done with a pi-tape, precision ≈ 0.2 mm
  - This info is used for the pairing for the stainless steel shells for welding (see for example MQXFBMT4, EDMS 2847270)



Summary

- Target for MQXFB08: reproduce MQXFB07 pre-load conditions (see EDMS 3173102)
- The target loading key thickness is 13.8 mm
- The target room temperature preload:
  - Average shell stress: 58 ± 6 MPa;
  - Average pole coil stress: - 80 ± 10 MPa
  - Rod strain: 650 με
  - This is a target not a requirement, and in case the maximum allowable peak stress in the conductor (110 MPa) is reached, the average pre-load will be lowered accordingly to fulfill the peak stress requirement
- Based on the experience gained with MQXFB assemblies, a series of observables are monitored along the assembly and compared to previous magnets to verify at every step that we reach our targets (EDMS 2872430)
  - Here we focus on geometrical and strain measurements, but field quality is also closely monitored, see additional slides.

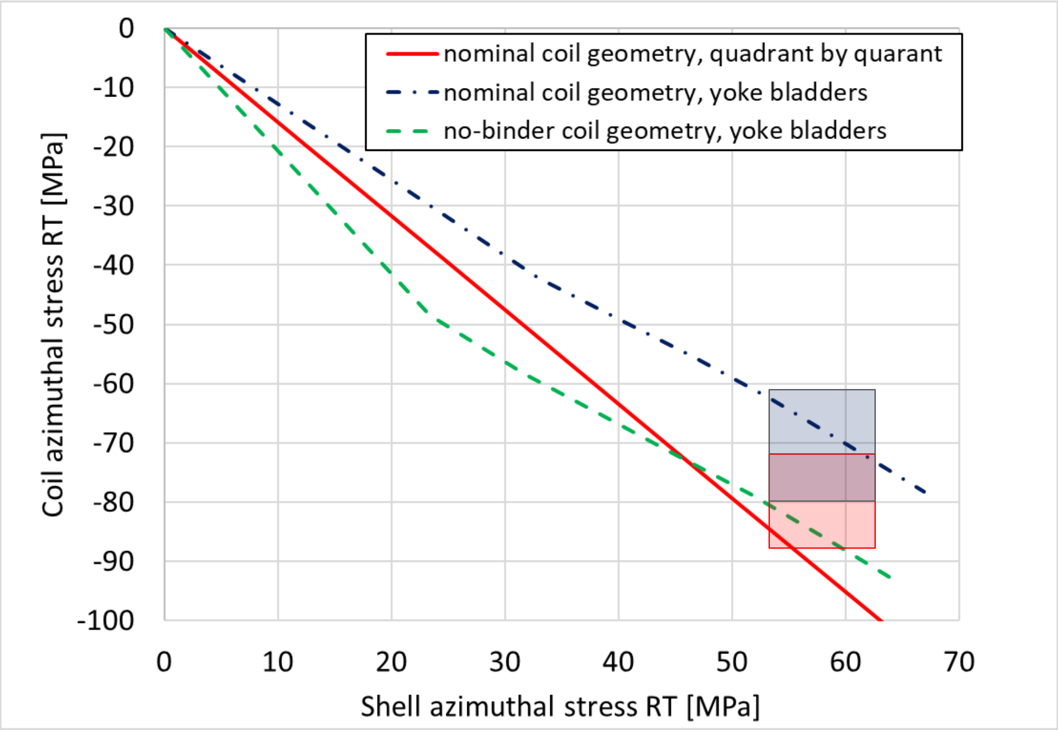
Thank you!

Additional slides

Reminder of impact on modifications in the TF

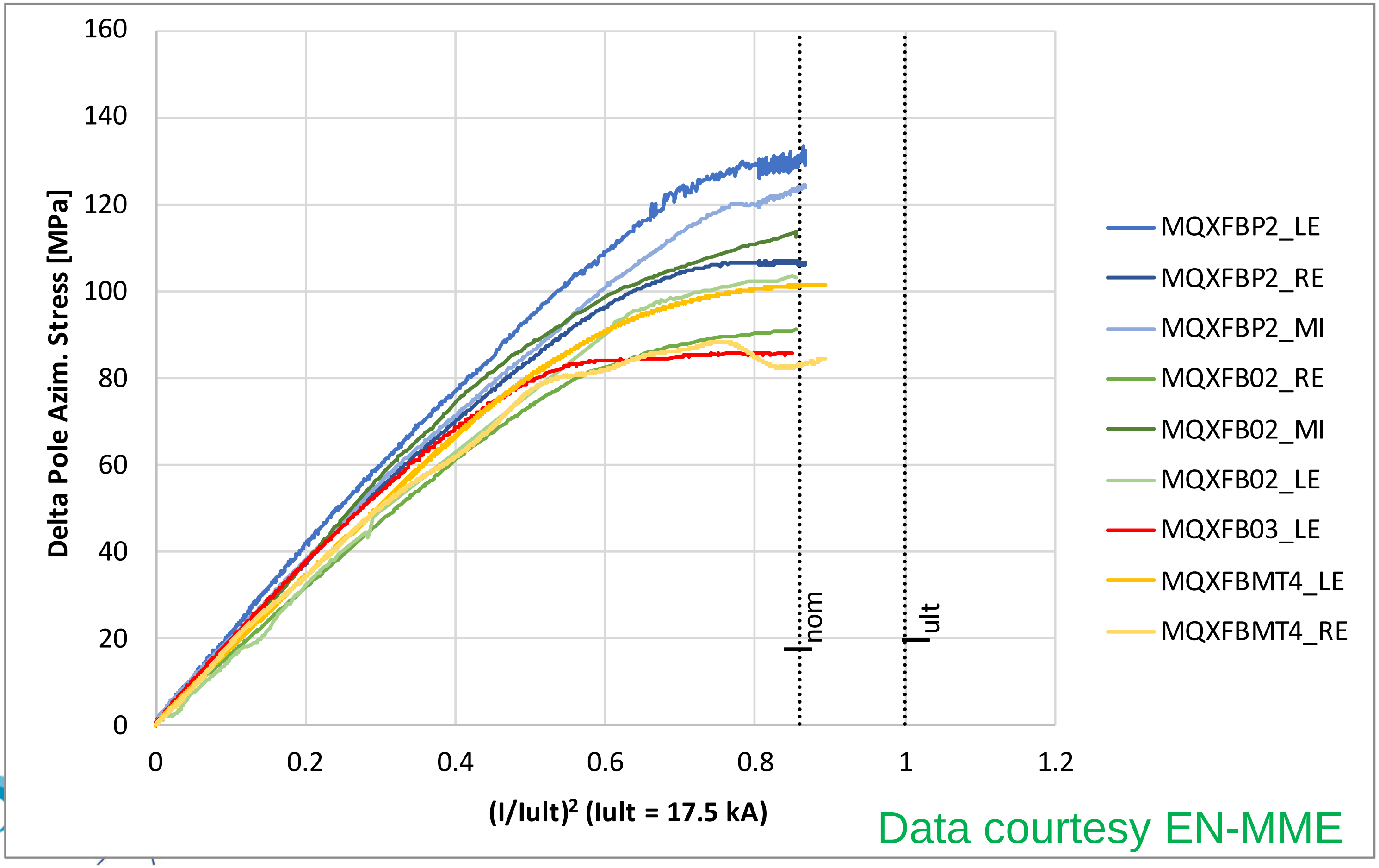
- With the new loading procedure (yoke bladders), we expect less pole stress at RT for the same shell stress → we modified the loading target in B02 to 70 +- 10 MPa (before it was 80 +- 10 MPa) (see https://indico.cern.ch/event/1158577/)

- With the new coil geometry (wedged mid-plane due to no binder in the OL), we expect 15-20 MPa more in the pole for the same shell stress (see https://indico.cern.ch/category/10520/)



Cold: Targets vs achieved

- At cold, MQXFB02 had 90-110 MPa pole azimuthal compression, corresponding to a pole un-loading around nominal current
- For MQXFB03, we only have ‘clean’ measurements from the LE end, 85 MPa.



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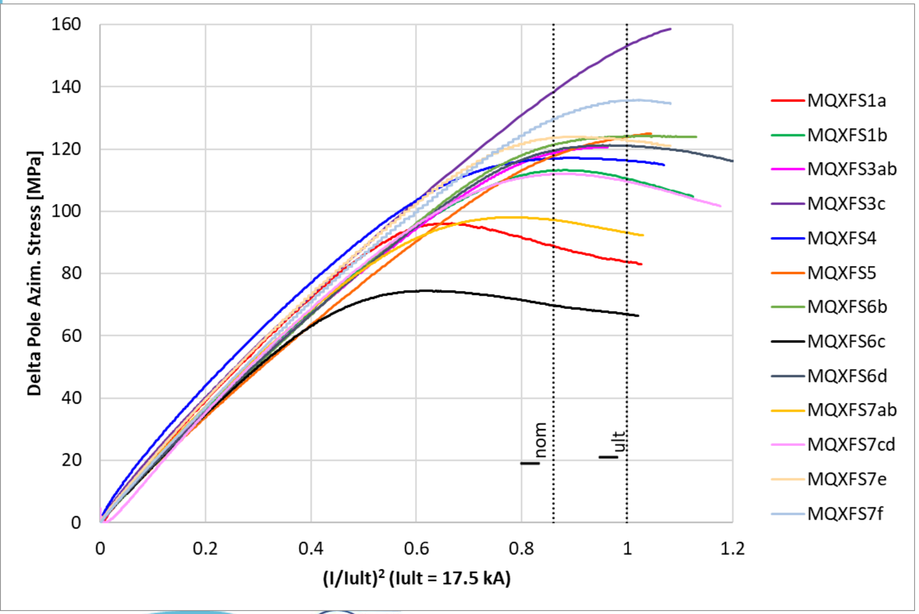
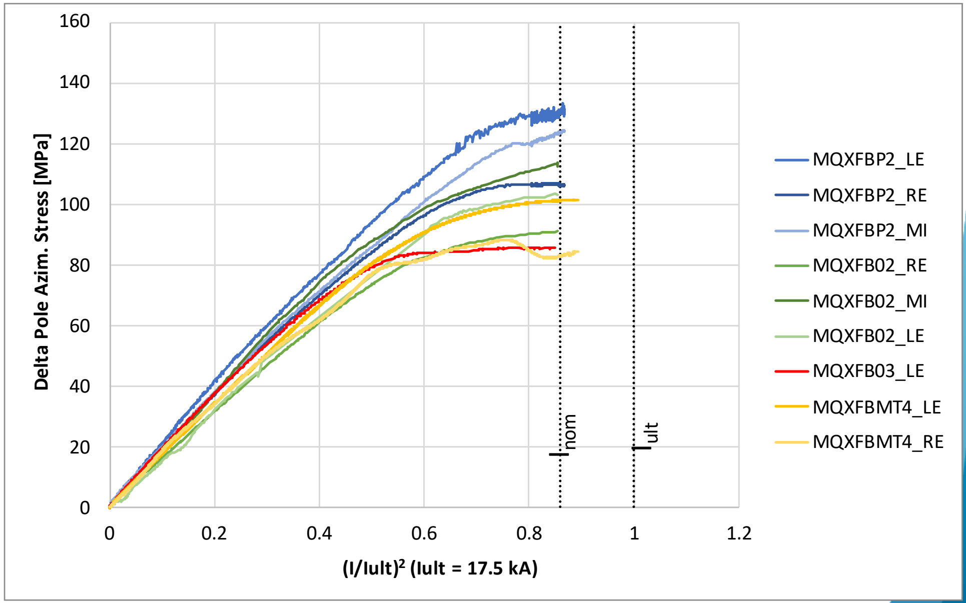
Cold: Targets vs achieved

- MQXFS explored a wide range of pre-load, with magnets reaching performance requirements with a pole azimuthal compression at cold of 70-180 MPa.
  - Low pre-load does not seem to be a limitation for performance, but might have an impact on the training (AUP has some evidences that magnets with higher pre-load train less, see Structure WG re MQXFA13 analysis and preload targets (September 5, 2023) · INDICO-FNAL (Indico))





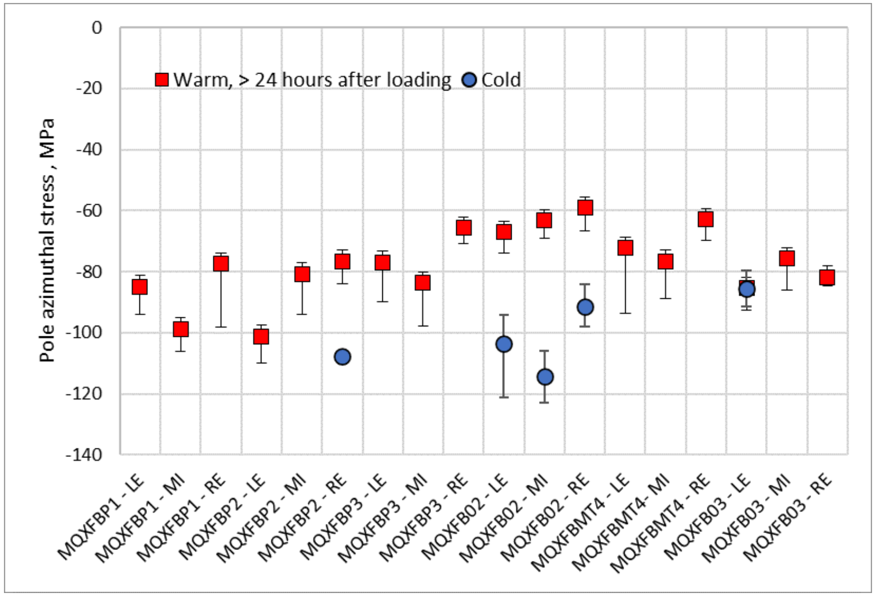
Data courtesy EN-MME

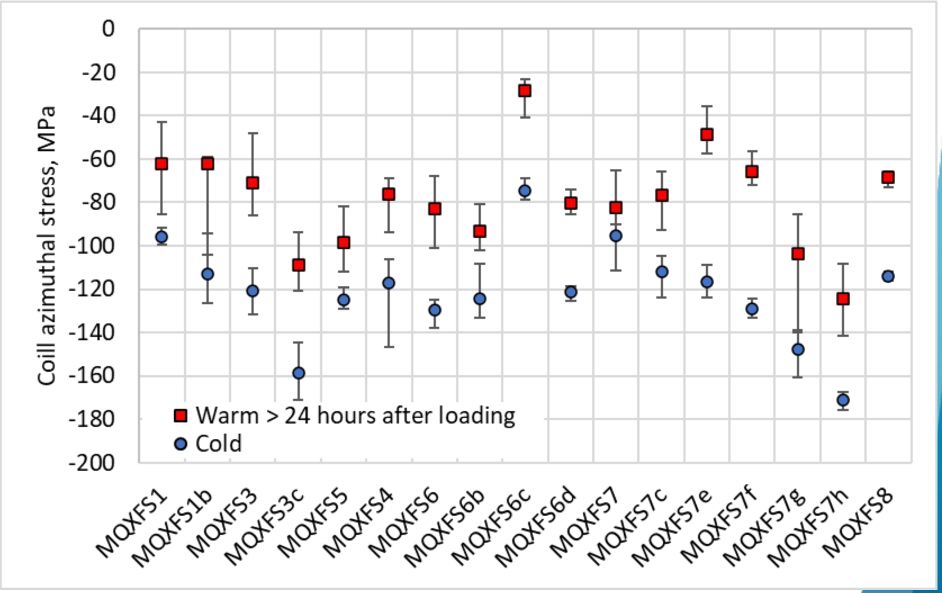
Cold: Targets vs achieved

- So far, we have very little data from B03, but we see basically no increase of the azimuthal pre-compression with the cool down (when deriving the pole compression from the delta powering)
- MQXFS explored a wide range of pre-load, with magnets reaching performance requirements with a pole azimuthal compression at cold of 70-180 MPa.

Estimated pole stress from delta powering, MPa

MQXFB03 - LE	C129	C130	C131	C128	AVE
Peak during magnet assembly	-87	-80	-63	-65	-74
> 24 hours after loading	-87	-92	-77	-86	-85
Cold	-80	-91			-85





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Axial pre-load

Instrumentation overview:

- **Strain gauges** placed on the rods
- **LVDT** used to monitor the rods displacement, they are a combination of LVDT used the rods and for end-plates and yoke. The combination of this measures is giving the actual rods displacement
- **Pressure sensor** to monitor the piston pressure during loading

Strain target: **650 ± 50 μstrain after loading** for MQXFB (for all the magnets we are in the ± 50 μstrain windows).

Do I need to always look at the strain data or can I relay on the other measures?

It's interesting to have equivalent targets for pressure and displacement to guarantee 650 ± 50 μstrain :

1. Pressure target: **300 ± 25 bar** (B03, B04 and B05)
2. Displacement target: **-5.33 ± 0.4 mm** (LVDT for B03 and B04 are not perfectly in contact, B05 is the first representative measurement)

Combing the targets of pressure and displacement, we can identify a 'safe' window to guarantee the strain target.

Conclusions:

- We have a really good correlation between the expected values of rods strain and displacement and the measured one for the last 3 magnets (B03, B04,B05)
- Rods instrumentation will be present in magnet B06 to confirm the data on the displacement
- For future assemblies, it will be sufficient to guarantee the strain target looking at the pressure and the displacement graph