MQXFB magnet assembly

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on behalf of the MQXF team

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Outline

- Introduction
  - Recap
  - What is new from last CM?
  - Timeline
  - MQXFB assembly
- MQXFB Assembly Observables
  - Coil pack sub-assembly
  - Yoke-shell sub-assembly
  - Loading
- Conclusion

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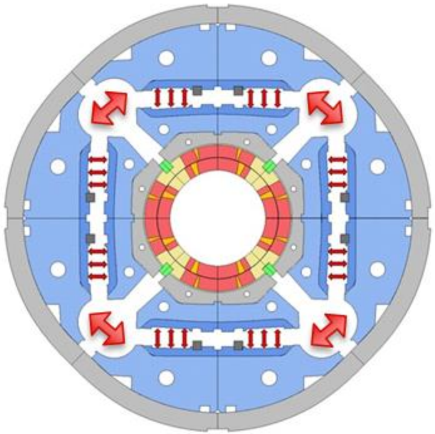
Recap

New assembly procedure with auxiliary bladders in the cooling hole channels

MQXF magnets are assembled using the bladders and keys procedure.

Starting from MQXFB02, auxiliary bladders in the yoke were used to keep the peak stress in the coil below 110 MPa.



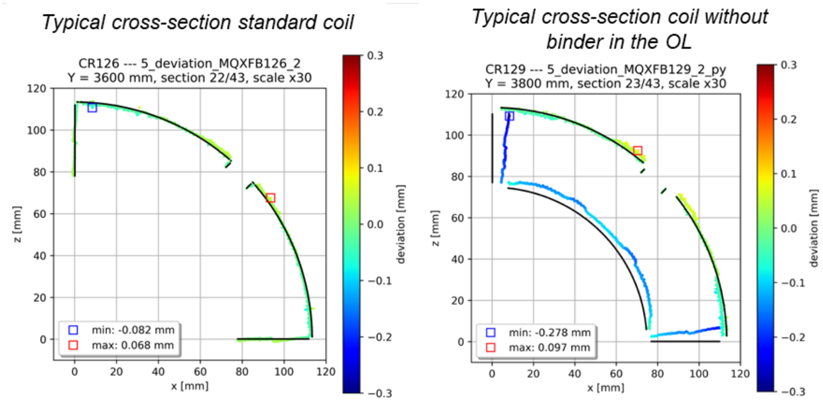
‘New generation’ coils

A series of modifications were implemented from MQXFB03 in the coil manufacturing process.

As consequences, the new coils:

- Are smaller than nominal, with no ’belly’
- Have a mid-plane angular deviation

After a series of analysis, the estimated difference between the two geometries is around 10/15 MPa.



What is new from last CM?

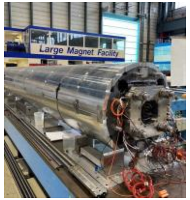
- 3.5 magnets assembled last year, all following the **new assembly procedure with auxiliary bladders in the cooling hole channels** and all having the **‘new generation’ coils**
- 1 magnet disassembled (due to NCR 2940210, QH to coil short in coil 124)

MQXFB04

Sept-Oct 2023

MQXFB02

Nov 2023 (disassembly)



MQXFB05

Feb-Mar 2024

MQXFB06

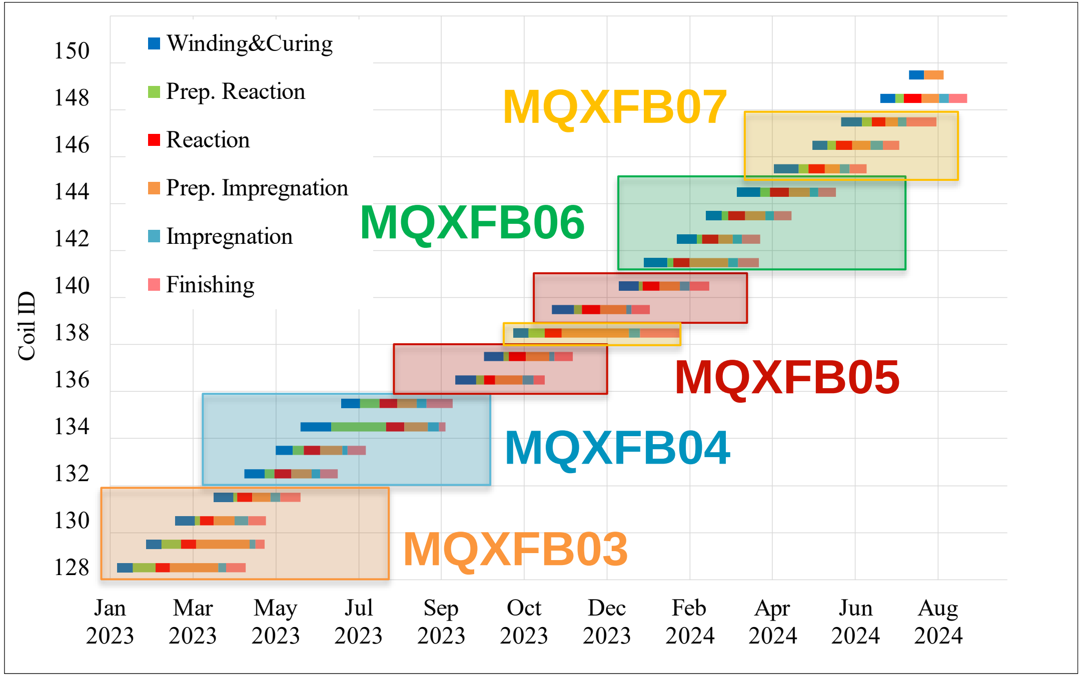
May-June 2024

MQXFB07

Sept-Oct 2024

Timeline

All the magnets assembled this year have ‘new generation’ coils.



MQXFB assembly

Magnet assembly can be divided in 3 steps:

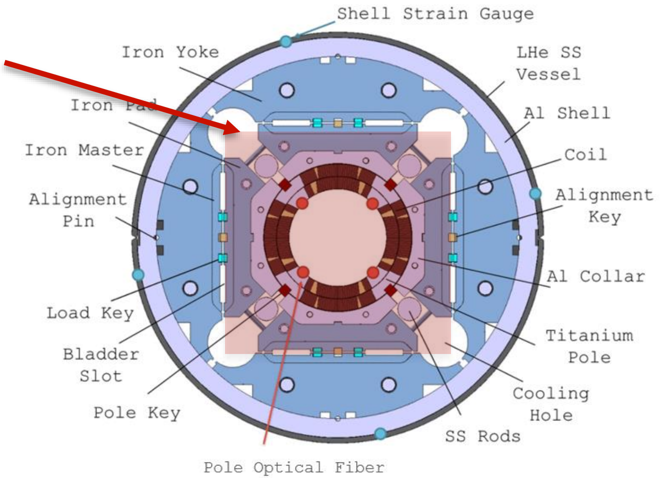
1. **Coil pack assembly**, which consists of four aluminium collars and iron pads bolted around the superconducting coils.
2. **Yoke-shell assembly**, composed by 5 moduli, each characterized by four iron yokes surrounded by a 29 mm thick aluminium shell.
3. **Loading,** with the purpose of providing the required pre-stress to the coil to reduce conductor motion. During this step, the coil pack, that is inserted in the yoke-shell structure, is pre-loaded with bladders and keys procedure.
   - The axial loading is done through a system of rods and thick endplates

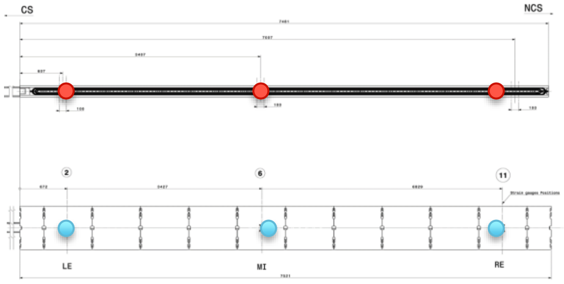
During all the assembly process, different measurements are performed and compared with the established acceptable ranges.

How do we measure?

- Pole optical fibers
- Shell strain gauges
- Rods strain gauges
- LVDT (dimensions, rods displacement, etc)
- Pressure sensors (bladders, rods hydraulic system , etc)
- Others

It is the first time that we have a series production characterized by this kind of structure, therefore all these measurements provides useful information about the assembly process.

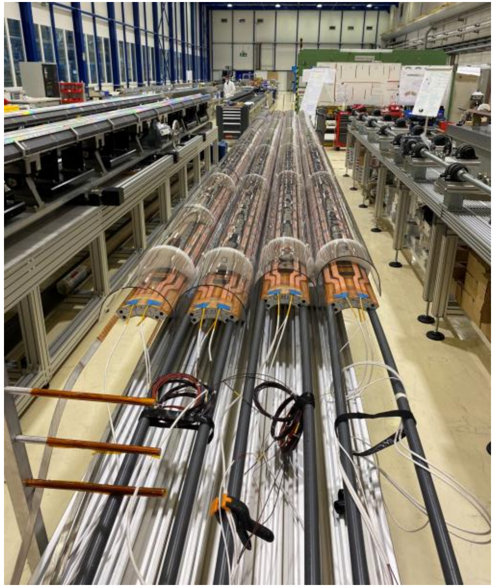


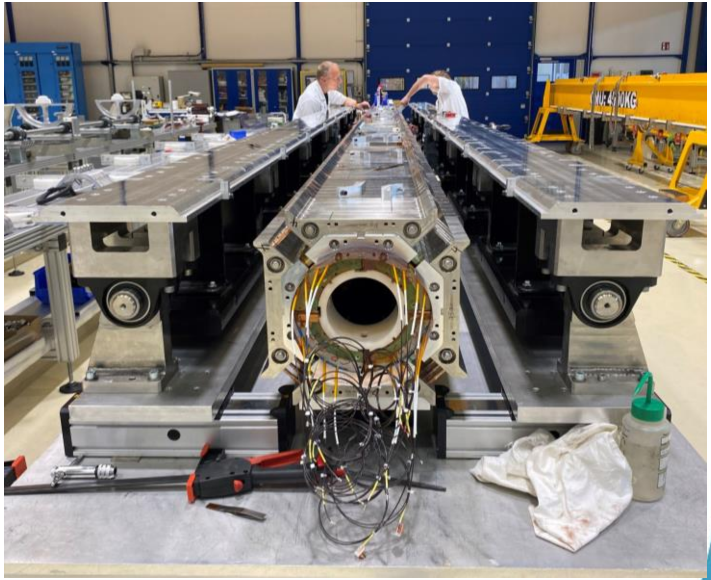


Coil pack assembly

When 4 coils are ready, we start the **coil pack assembly**:

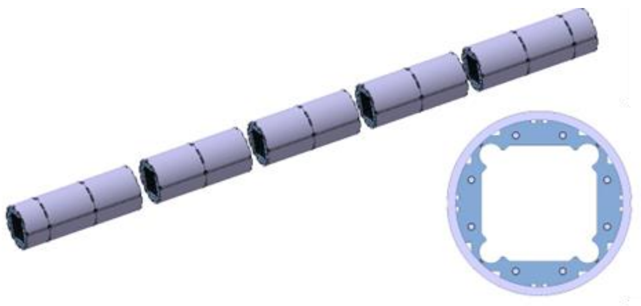
- The difference in size among the coils is compensated with radial and azimuthal shims of polyimide.
- Aluminium collars and iron pads are bolted around the coils. The collar does not have a mechanical function, acts as an ‘spacer’.





Yoke-shell assembly

- Yoke-shell subassembly is composed of 5 modules, assembled vertically
- The 5 modules are then assembled horizontally and compressed to have a packing factor ≈ 100 %
- Then, the coil pack is inserted in the yoke shell structure



Loading

The loading is characterized by:

- **Azimuthal loading**, using the bladders and keys procedure.
- **Axial loading**, pulling the rods with the hydraulic pistons.

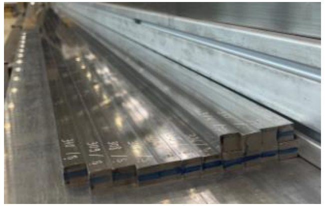
During loading, the strain (stress) in the pole and in the shell is constantly monitored via strain gauges and optical fibers.

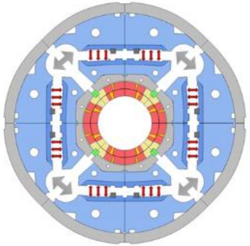
The **transfer function(TF)** between coil stress and pole stress is a tool that we use to ensure that

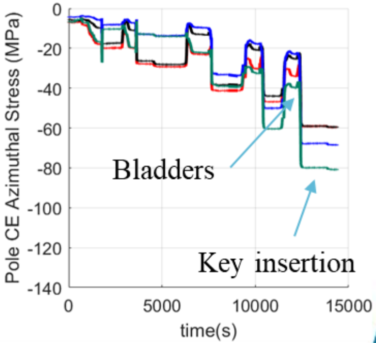
- both components are operating within their acceptable stress limits
- the expected target preload is reached

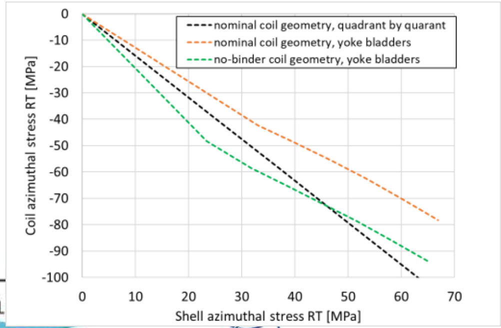
The expected TF is calculated via FEA analysis and thanks to the model we can predict:

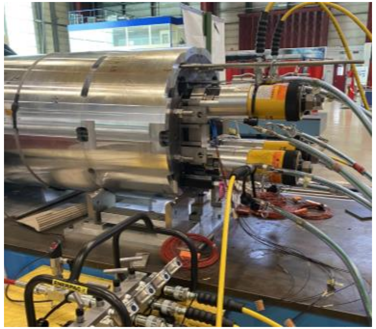
- The change of slope using the new assembly procedure with auxiliary bladders in the cooling hole channels
- The change of slopes due to the new generation coils











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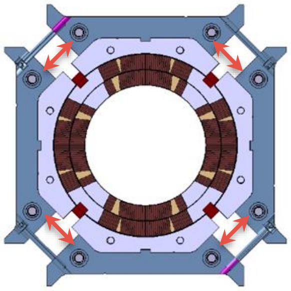
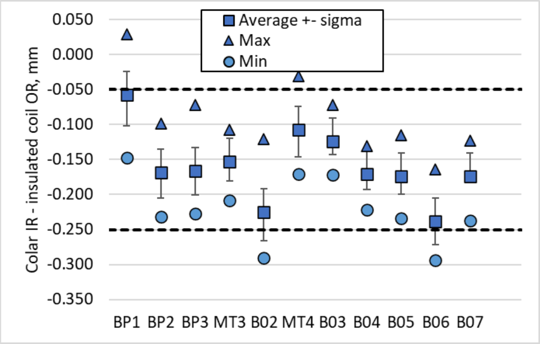
Coil pack sub-assembly

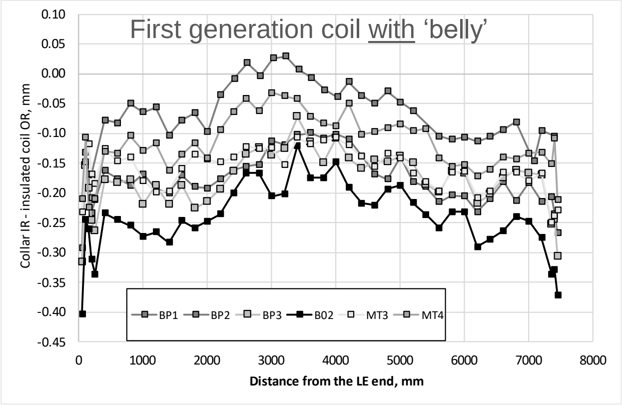
Coil pack sub-assembly

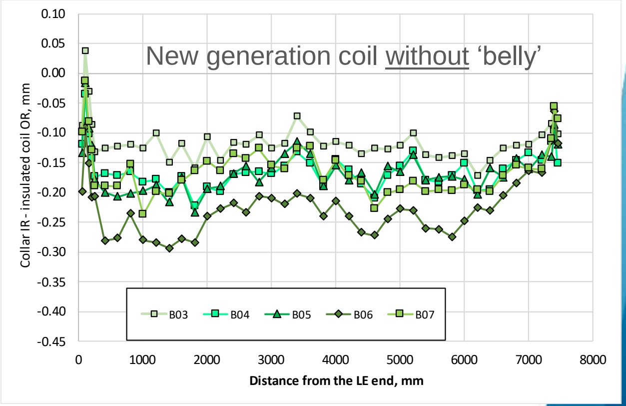


The gap between collars and insulated coils with respect to the nominal dimension gives information about the **coil pack radial size**.

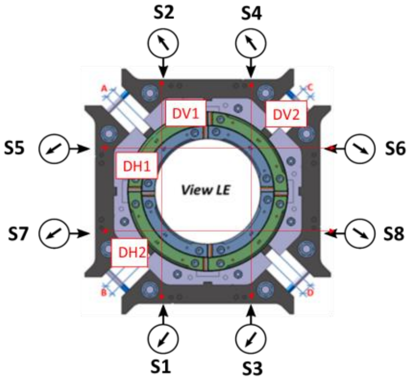
- The magnets with the new generation don't have the 'belly' (larger azimuthal size in the longitudinal center of the coil), and they have very similar sizes.
- The size of the coil pack can be now controlled up to 0.05 mm. For example, B06 is smaller (0.075mm) on purpose, to have the ends' size similar to the previous magnet.







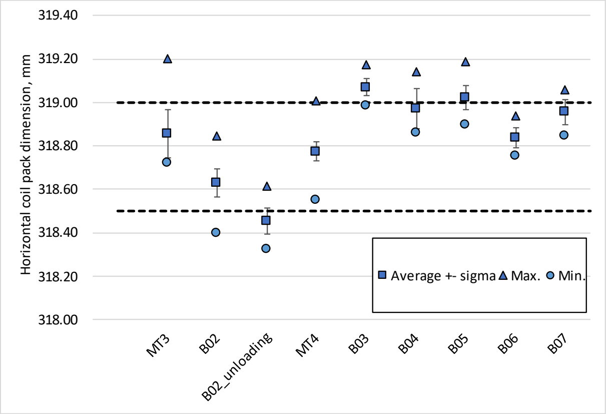
Coil pack sub-assembly

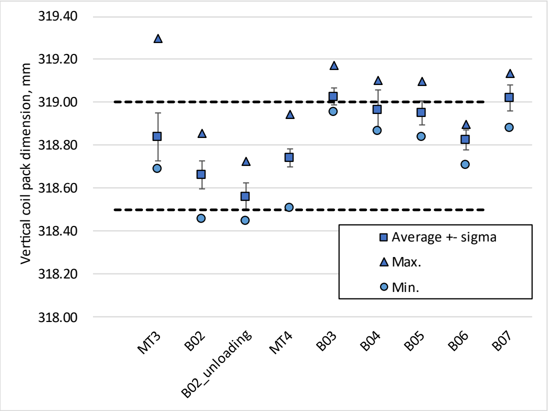


The coil pack is measured horizontally and vertically before the insertion in the structure.

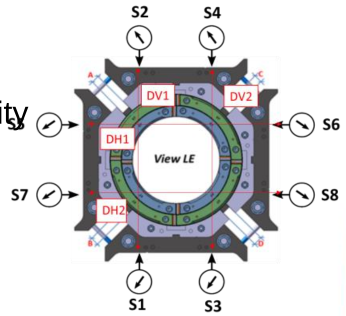
- The differences in the **dimensions** of the coil pack are the same as the one seen in the coil pack radial size (Ex. B06 0.075mm smaller)

Dimensions





Coil pack sub-assembly

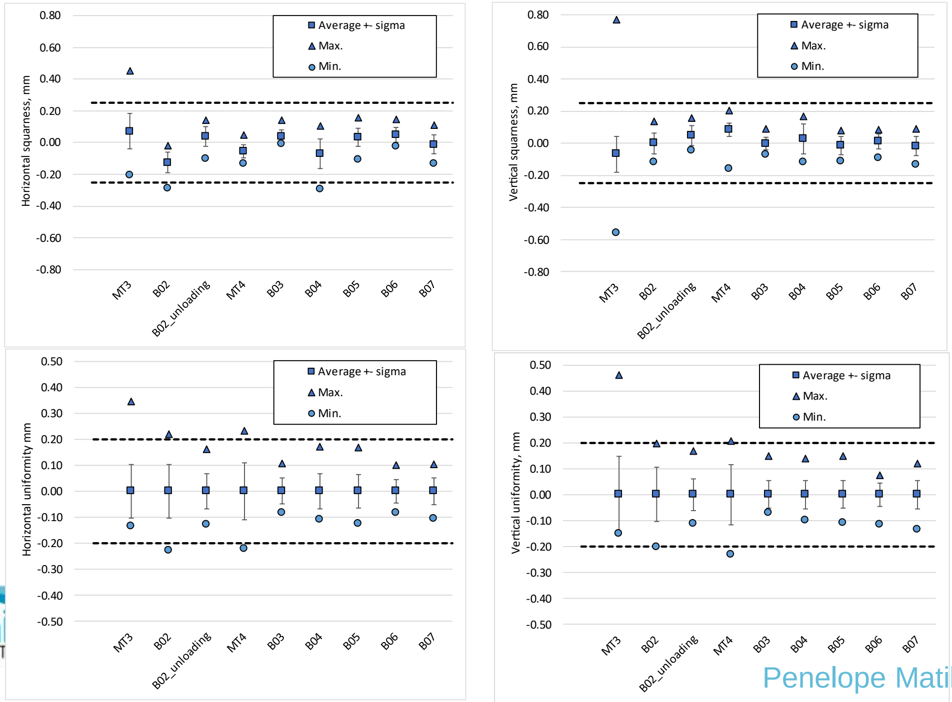


From the measurements it is possible to derive **squareness** ,defied as the difference between the left and right or top and bottom dimensions, and **uniformity**, defied as the average of the vertical or horizontal cavity dimension in each cross-section with respect to the measured average horizontal dimension :

- The **squareness** is consistent with the previous magnets
- The **uniformity** improved with the new generation coils (coils are more uniform along the length now)

Squareness

Uniformity



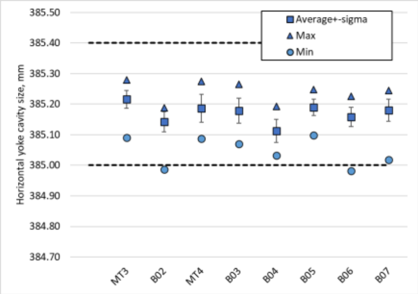
Yoke-shell sub-assembly

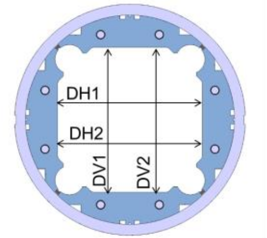
Yoke-shell sub-assembly

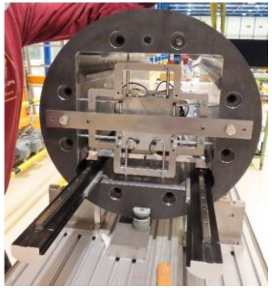
Both the moduli and the final structure are measured to have information about size, squareness and uniformity. Here is presented just the structure analysis.

For the yoke-shell assembly, the magnets are consistent, there is an improvement in the squareness.

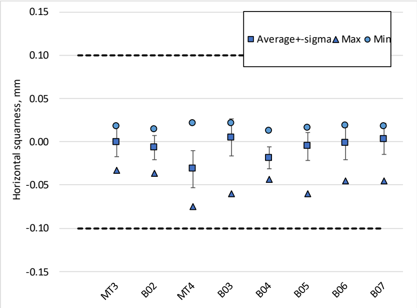
Dimensions

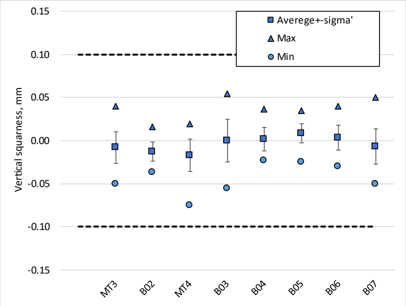




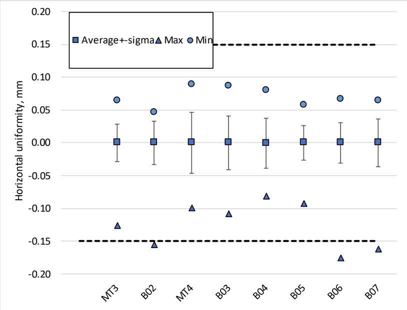


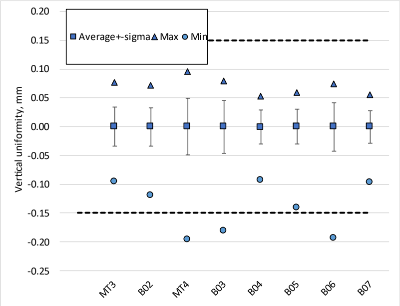
Squareness





Uniformity





Loading

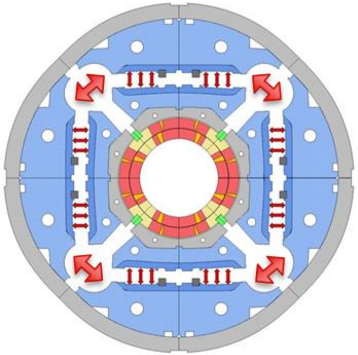
Azimuthal pre-load target (from B03 on)

Loading has the purpose of providing the required pre-stress to the coil to reduce conductor motion.

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**
- 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)
- 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



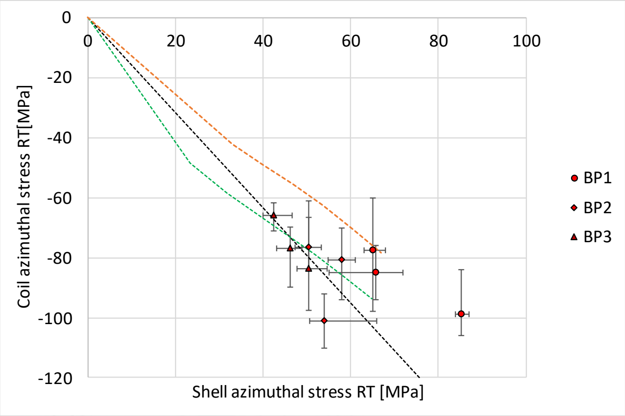
RT transfer function evolution

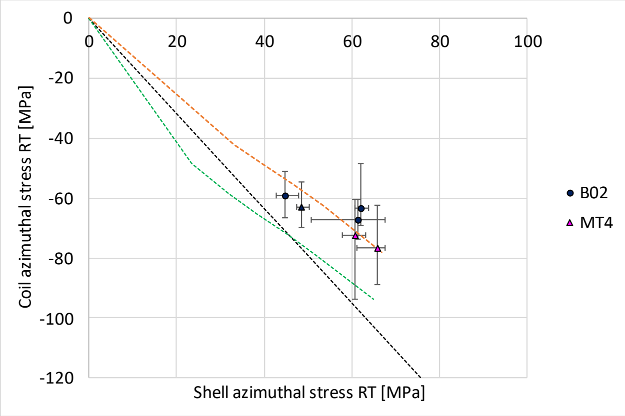
So far, relatively good agreement between expected transfer function and measured transfer function

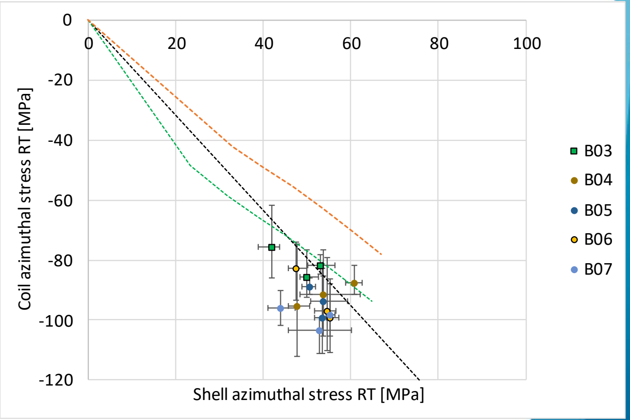
- In B02/MT4 we show the change of slope due to the new loading procedure (orange dashed line)
- From B03 we are closer to the original slope (black dashed line) due to the 'new coil geometry' (green dashed line)
- Looking at the averages stress after loading (table), they are rather unifrom, but there 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

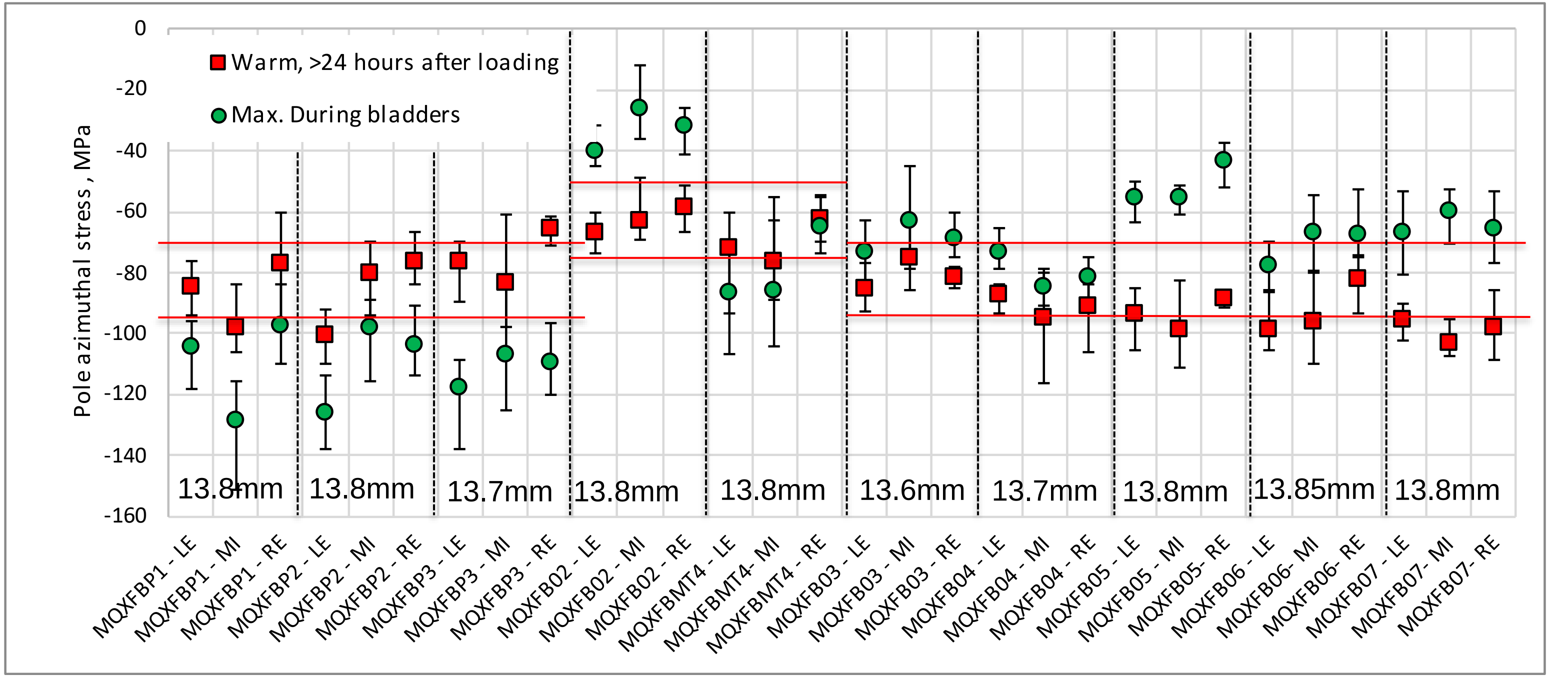






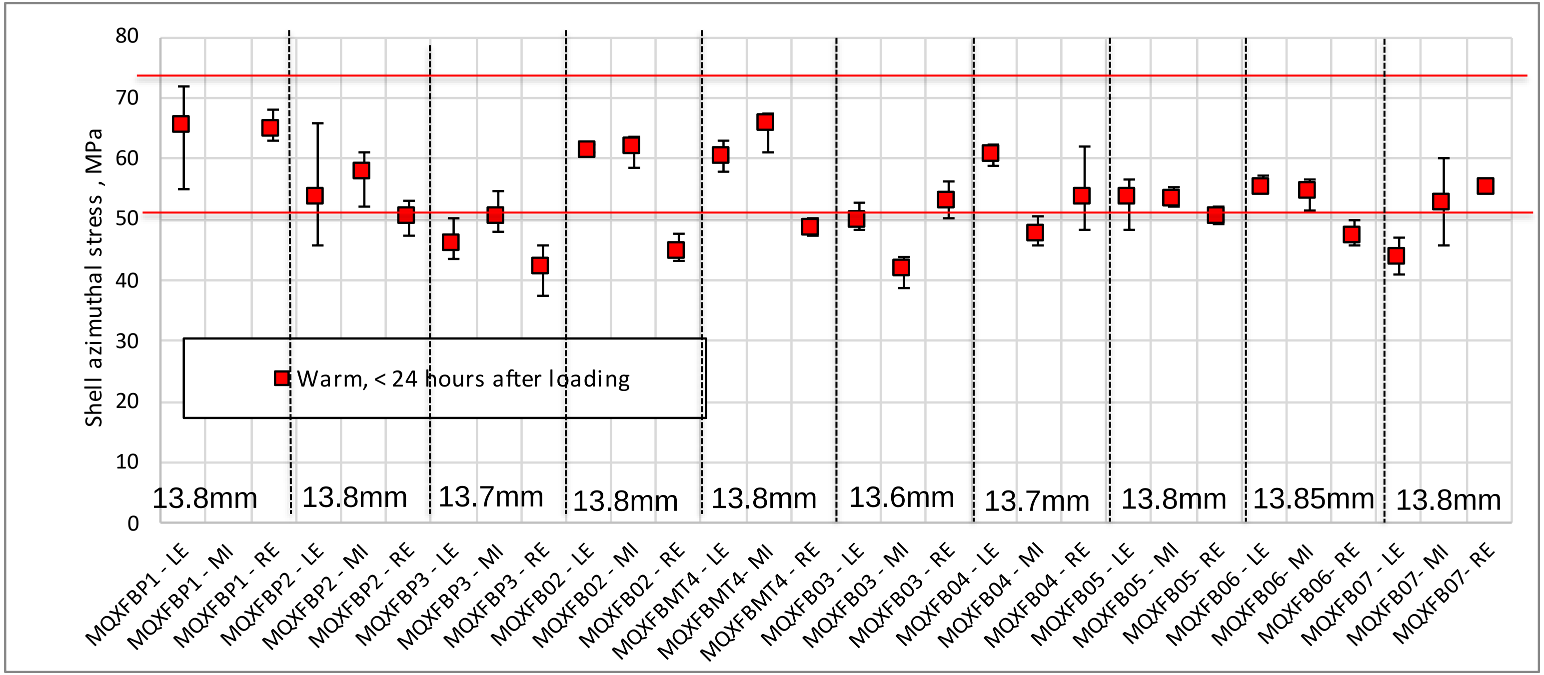
RT: Targets vs achieved

- From MQXFB02, auxiliary bladders in the yoke were used to reduce the peak stress in the coil and from MQXFB03 the new generation coil geometry is used



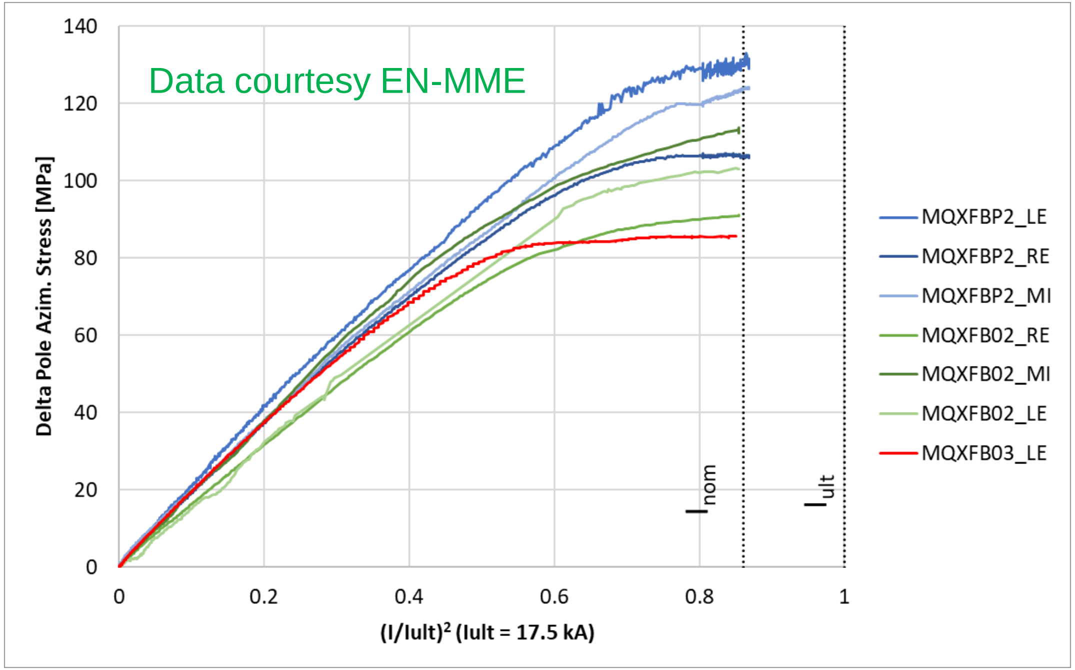
RT: Targets vs achieved

- The shell has similar behaviour in all the magnets



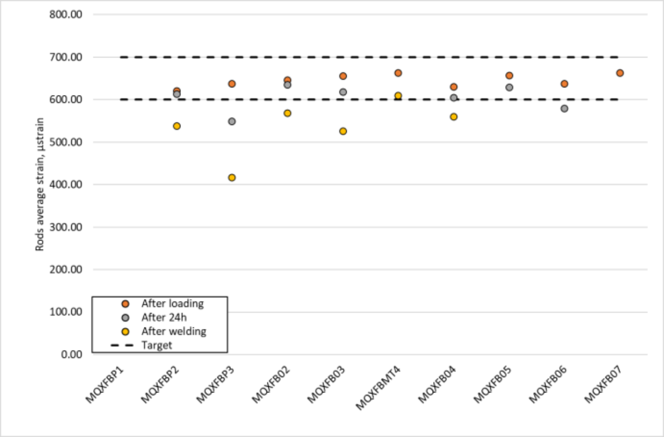
Cold: Targets vs achieved

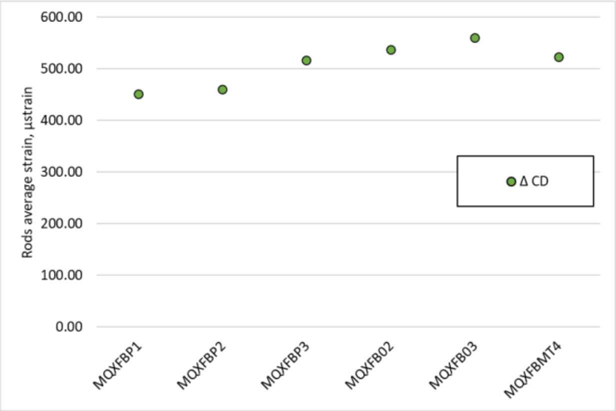
- At cold, MQXFB02 had 90-110 MPa pole azimuthal compression, corresponding to a pole un-loading around nominal current
- For MQXFB03, we only have ‘clean’ measurements from the LE end, 85 MPa (Remember, B03 has keys 13.6 mm, the smallest used so far).
- From MQXFB04, there are no stress measures at cold

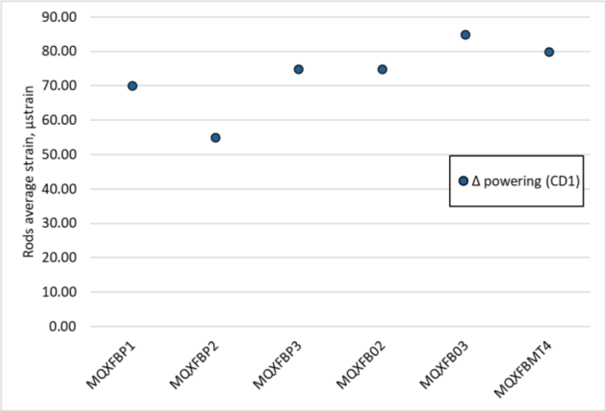


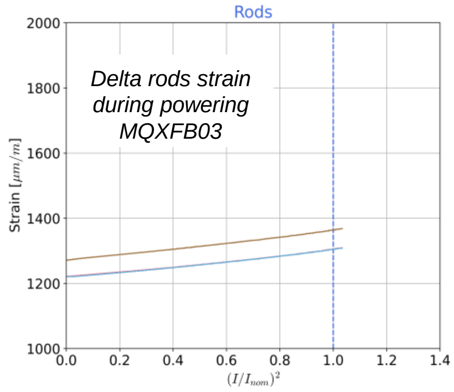
Rods, axial pre-load

- From BP2, all magnets loaded so far with the same axial pre-load (at RT), 650 ± 50 µstrain **after loading**
- **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 has similar behaviour to the previous magnets, although now the magnet is mostly quenching in the ends



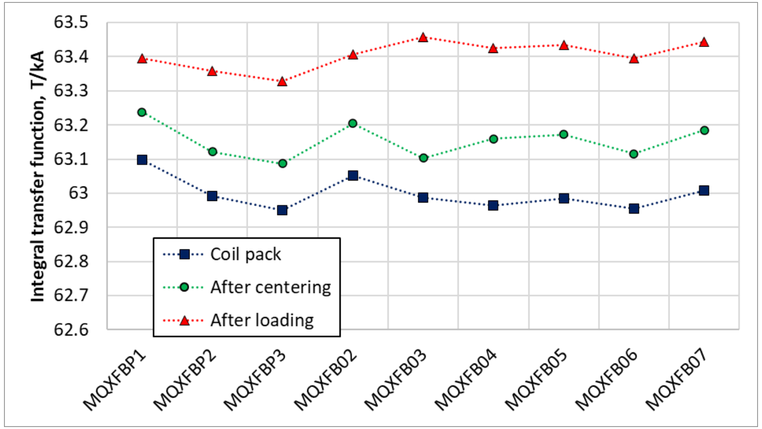


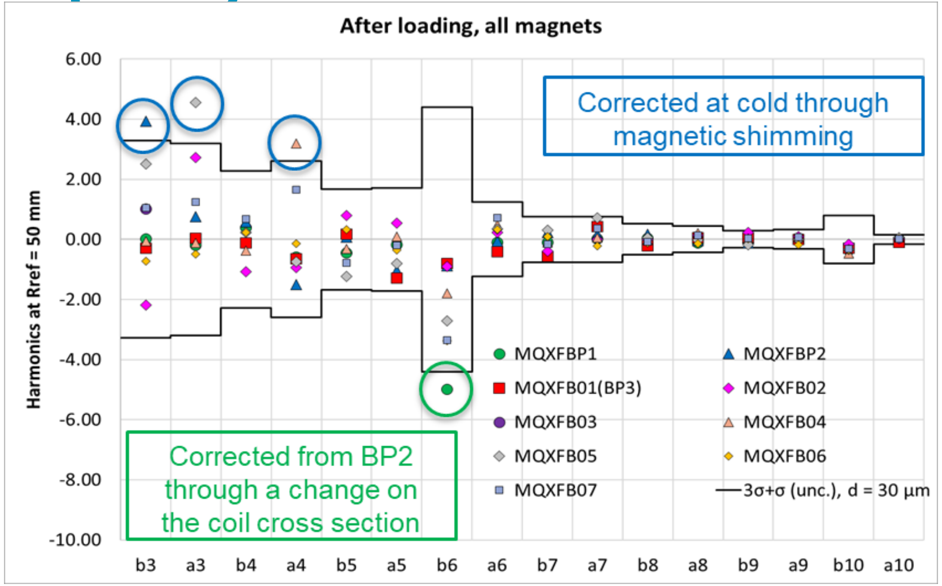




Field quality

- Field errors well within the requirements, with good cold/warm correlation and ability to correct field errors through magnetic shimming
- Integrated gradient after loading is within a range of 20 units, as required, already in this early phase
- With the new generation coils we were expecting -2.2 units of b6, and that we are actually seeing it.





After loading

	B07	B06	B05	B04	B03	B02	BP3	BP2	BP1
b6	-3.35	-3.37	-2.03	-1.79	-1.43	-0.9	-0.58	-0.89	-4.99

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Conclusions

- The assembly of MQXFB magnets is well established, no major changes have been done since last CM
- From MQXFB03, all magnets have a very similar coil pack size, thanks also to good reproducibility of the coils
- There is a good agreement between expected transfer function and measured transfer function of the magnet loading for the magnets with the new generation coils. Still, there is a significant spread on the measured stress after loading.
- The observables show the reproducibility of the production with similar results for the past 5 magnets (delivery rate of 3 magnets per year)
- We didn’t have any critical non-conformities this year


Large
CERN