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Analysis of the mechanical performance of the 4.56 m long MQXFA Pre-Series magnets for the Hi-Lumi LHC Upgrade

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Abstract

Under the U.S High Luminosity LHC Accelerator Upgrade Project (HL-LHC AUP), the 4.56 m long, 150 mm bore, high-field Nb_3Sn low-β MQXFA quadrupole magnets are being fabricated, assembled and tested, in the context of the CERN Hi-Luminosity LHC (HL-LHC) upgrade. To date, eight magnets (MQXFA03 through MQXFA11, except MQXFA09) have been tested. In addition, MQXFA05 successfully underwent an endurance test with 40 triggered quenches. MQXFA07 and MQXFA08 did not perform as expected. This work summarizes the available strain gauge data from the structure of the tested magnets, focusing on the MQXFA05 tests, and on the possible causes of under performance of MQXFA07 and MQXFA08. We applied methods to prevent these events from happening in future MQXFA magnets, which shown to be effective for MQXFA10 and MQXFA11.

Acknowledgements

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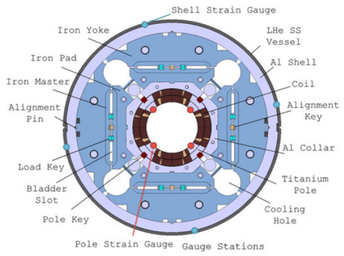
Conclusions

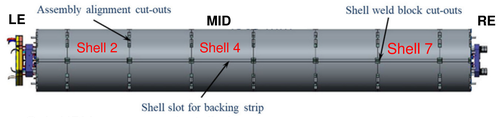
MQXFA05 showed an outstanding performance even when there was a non conformity with the rods' material (lower yield strength). The strain gauge data cannot explain the underperformance of MQXFA07 and MQXFA08; this might be a consequence of the long distance between the strain gauge location (RE) and the quench location (LE) in both magnets. The new methods applied to control the squareness of the coil-pack resulted in a more uniform axial strain increase of the four coil quadrants in MQXFA10 and MQXFA11 during magnet excitation.

Introduction

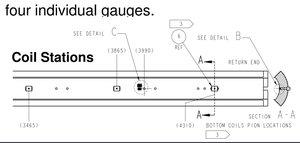
- The MQXFA magnet yoke length is 4.56 m.
- Eight magnets MQXFA03 through MQXFA11, except MQXFA09) have been assembled and tested.
- MQXFA05 successfully underwent an endurance test with 40 triggered quenches.
- MQXFA07 and MQXFA08 did not pass the vertical test, and the limiting coil was Q3 in both cases.
- MQXFA09 structure parts were rebuilt into MQXFA11. MQXFA11 is being tested.
- MQXFA08 is now MQXFA08b, where only the limiting coil was replaced by a new coil (not tested yet).

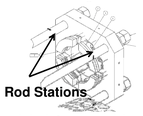


Cross section of the MQXF magnets and location of the strain gauges



- Only HBM gauges are installed.
- Shell gauges --- three axial locations (T & Z): on shell 2, 4, & 7
- Coil gauges (T & Z): on the axial location of 3989 mm (RE) from LE.
- Rod stations are located on the RE, each station is full bridge with four individual gauges.





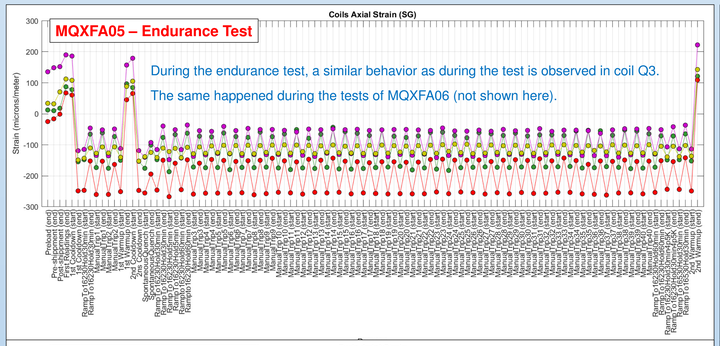
RE axial plate assembly

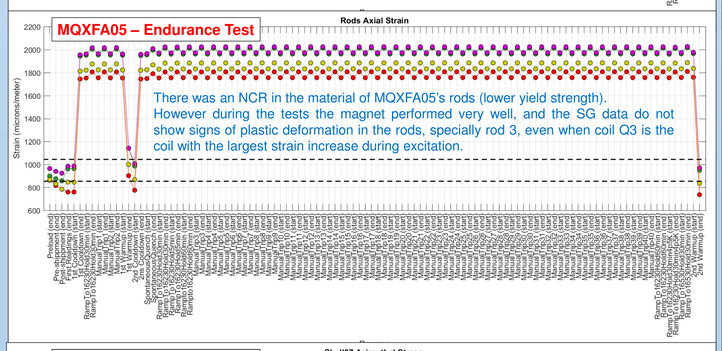
Summary of key points

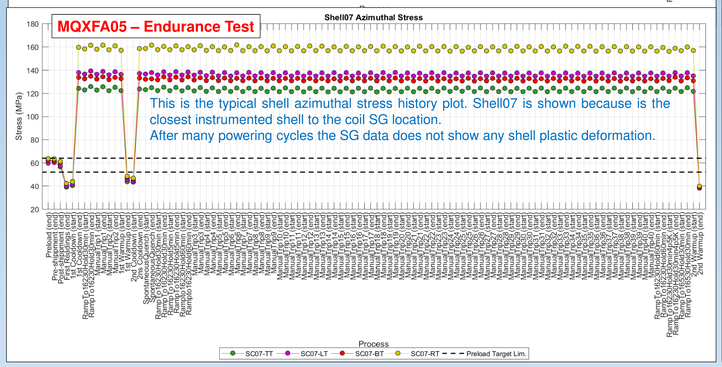
- During the first test and a long endurance test with 40 manual trips, MQXFA05 showed an outstanding performance. The rods and the shells present a very consistent behavior, and no signs of plastic deformation, which suggests the desired level of prestress to the coils will be maintained for the magnet's lifetime, even when the rods presented an NCR during fabrication (SS 316L with lower yield strength).
- In all the magnets before MQXFA10, the axial strain in the coils is not uniform during powering, with the axial strain in coil Q3 being one of the largest in all magnets. However, this is not reflected in the behavior of the rods.
- After the test of MQXFA07 and MQXFA08, it was observed that the pole key gap corresponding to coil Q3 was closed. FEA models showed this condition can cause the azimuthal stress from the shell to not transfer to the titanium pole and to the coil Q3. The subsequent methods applied to MQXFA10 and A11 for maintaining uniform pole key gaps in the coil-pack resulted in a more uniform strain increase in the four coil quadrants during the magnet excitation.
- The coil azimuthal stress during excitation in the tested magnets MQXFA03 through A11, is in average ~100 MPa.

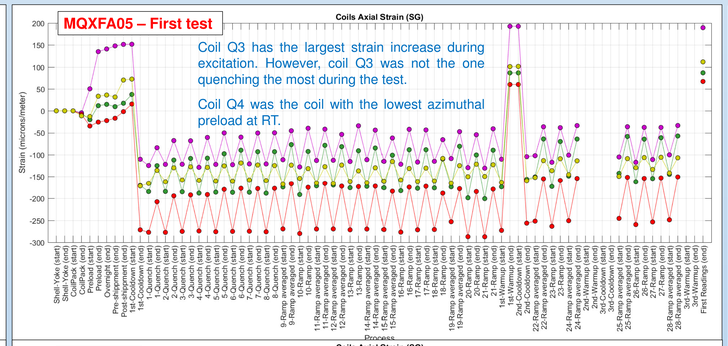
For details on possible causes of underperformance of the MQXFA07 and A08 magnets, refer to **G. Ambrosio, 1LOr2A-02, ASC 2022**.
For details on CMM measurements and methods for squaring the coil-pack, refer **to K. L. Ray, 3LPo1A-02, ASC 2022**.
For details on preload targets at RT and preload operations at RT of the MQXFA magnets, refer to **D. Cheng, 2LOr2A-02, ASC 2022**.

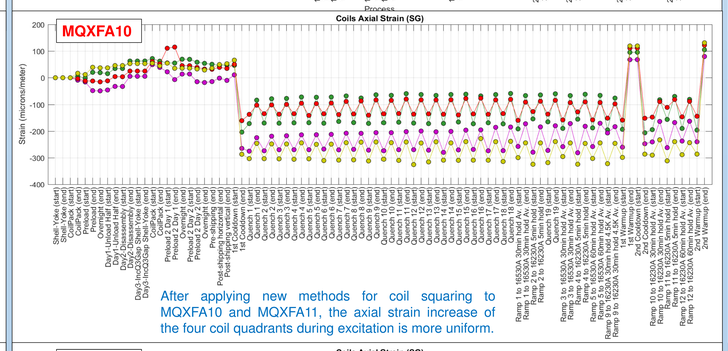
Magnet History Plots

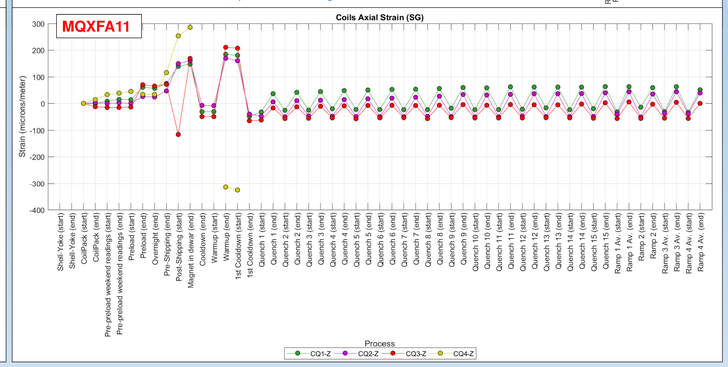


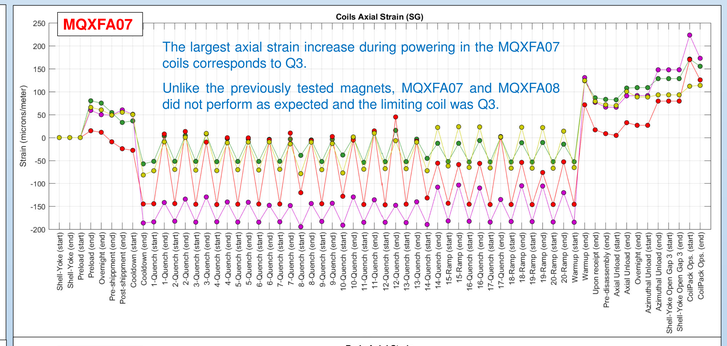


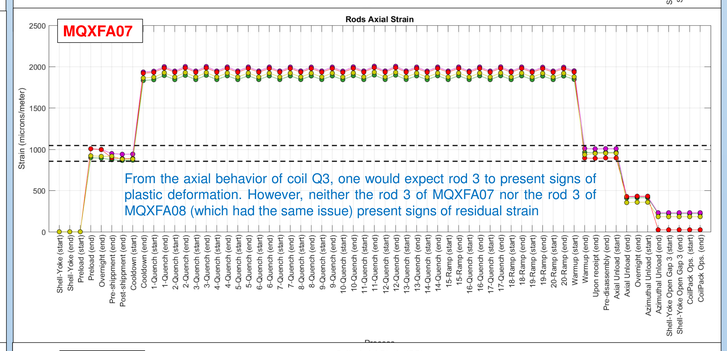


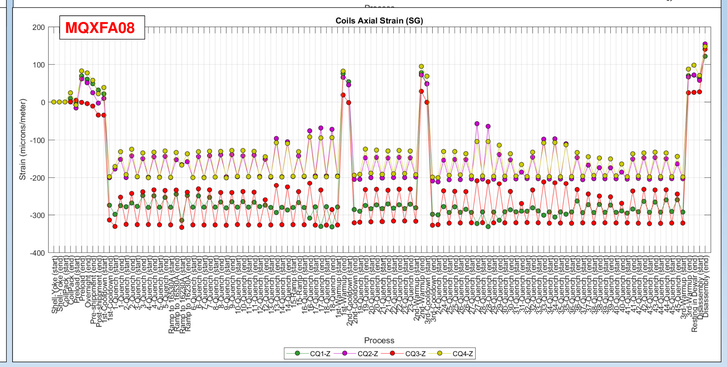






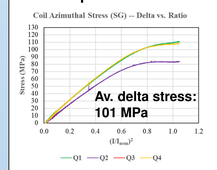




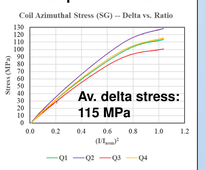


Coil Azimuthal Stress Increase During Powering (Ramps-up and down averaged)

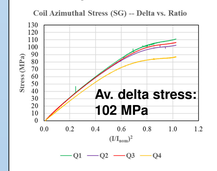
MQXFA03
Ramp to 16.65 kA



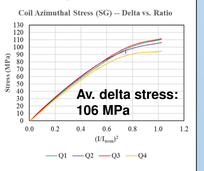
MQXFA04
Ramp to 16.55 kA



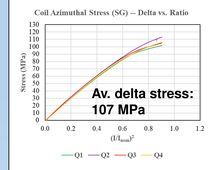
MQXFA05
Ramp to 16.46 kA



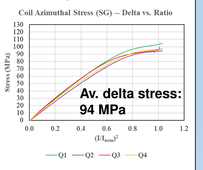
MQXFA06
Ramp to 16.45 kA



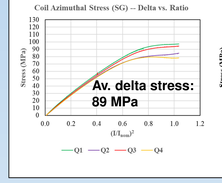
MQXFA07
Ramp to 15.45 kA



MQXFA08
Ramp to 16.50 kA



MQXFA10
Ramp to 16.54 kA



MQXFA11
Ramp to 16.54 kA