US HL-LHC Accelerator Upgrade Project

MQXFA10 Coil Acceptance Review

TABLE OF CONTENTS

1. Goal & scope

The HL-LHC AUP project is planning to start assembly of MQXFA10 magnet in September 2021. MQXFA10 is the third series low-beta quadrupole magnet (MQXFA) for the Inner Triplet of the High Luminosity LHC. If MQXFA10 meets MQXFA requirements [1] it will be used in a Q1/Q3 cryo-assembly to be installed in the HL-LHC.

For MQXFA10 assembly (including a spare coil) AUP is planning to use QXFA coils: 129, 131, 132, 220 and 221. Coil 129 was approved for use in MQXFA09 [2] and is assumed approved for use in MQXFA10.

Conductor and series coil specifications are presented in [3-7]. Discrepancy or Non-conformity Reports are generated whenever a component does not meet specifications.

The reviewers are requested to review discrepancies and non-conformities in strands, cables and coils, for the following coils: 131 (cable P43OL1141), 132 (cable P43OL1146), 220 (cable P43OL1135), and 221 (cable P43OL1143).

2. Charge questions

The committee is requested to answer the following questions:

1. Have Discrepancies and Non-conformities been adequately documented and processed?
2. If there are critical Discrepancies/Non-conformities, have they been adequately documented and processed?
3. Did the L3s properly identified critical Discrepancies/Non-conformities?
4. Is there any coil that you recommend not to use in MQXFA10?
5. Do you have any other comment or recommendation regarding these coils and their conductor for allowing MQXFA10 to meet MQXFA requirements [1]?

Charge questions

The committee is requested to answer the following questions:

1. Have Discrepancies and Non-conformities been adequately documented and processed?

Yes. The non-conformances observed for cables were all judged to be minor and unlikely to affect coil dimensions.

FNAL Coils 131 and 132: Discrepancies in coil winding, reaction and impregnation steps were carefully noted for these coils.

For Coil 131 several DR's were recorded; none critical. It is noted that the reaction control was still inadequate (DR 12313, DR 12334). However, it is noted that the furnace improvement campaign has progressed sufficiently such that DR's related to furnace control should be absent in future coils. It is noted that the non-conformance in reaction temperature control for coil 131 was verified by witness sample measurements

For Coil 132 a CDR was recorded after impregnation. A small section of the blanket was wedged between the mid plane shim and the last turn of the coil. The cause was identified. However, it was deemed that no corrective action was necessary. Extra care will be exercised for future coils.

BNL Coils 220 and 221: Here too all discrepancies were recoded and where required, corrective action was implemented.

For Coil 220 one CDR was recorded; coil to pole short. It was traced to an area of contamination on ramp insulation and interlayer insulation. A repair was made before impregnation. *This is cause for concern* as a similar short was observed for Coil 216 due to a similar reason. It is not clear why this exact fault shows up in the coils. Are any further corrective procedures implemented for future coils?

For Coil 220, DR's were also recorded due to the presence of *popped strands* during L2 winding. This observation adds to that of other coils where popped strands and "collapsed cable" have occurred at BNL during coil winding.

For Coil 221 one CDR was recorded. This was related to protruding pole pin at the NL end of segment 8. Subsequently a second protruding pin was found during coil reception at LBNL. This defect will be accommodated by LBNL during coil prep and assembly.

If there are critical Discrepancies/Non-conformities, have they been adequately documented and processed?

Yes

The critical discrepancies and non-conformance to specification were adequately recorded and processed.

2. *Did the L3s properly identify critical Discrepancies/Non-conformities?*

Yes.

3. *Is there any coil that you recommend not to use in MQXFA10?*

AUP needs to decide on the choice of whether to use 129 instead of one of the FNAL coils 131 or 132 or the BNL coils 220 or 221.

Dimensionally, all coils were within tolerances. However, Inner Radius coil deviations (excess material) are observed for coil 220. The coil bumper thickness could be corrected to compensate. It appears that previous BNL coils have exhibited similar features – Coil 215, 216 and 217.

This issue alone is not enough to cause concern. However, combined with popped and loose strands in the cable during winding and the critical non-conformity which required an important repair operation after reaction, the committee recommends not using coil 220 at this time. It is still possible that, following feedback from MQXFA07 investigations, this coil could be used for a future magnet. The final disposition should be made pending the analysis of MQXFA07.

5. *Do you have any other comment or recommendation regarding these coils and their conductor for allowing MQXFA10 to meet MQXFA requirements [1]?*

Comments

<u>Strand and Cable</u>

All cables are dimensionally within specification and fairly uniform. It was noted that cable 135 shows more scatter in cable thickness than the other cables. This may be related to the pair of rollers used.

Although no Coil-reaction witness sample tests were presented, we find that, based on history of the pre-series coils, the expected cable performance should have significant margin at operating current and temperature to ensure easily reaching the required operating current. This has been demonstrated for the pre-series coils.

Except for Cable 135, Cable insulation at NEEWT show good consistency in the thickness measurements done at the vendor and those that were performed at LBNL and is within specification. Cable 1135 measured 0.002 mm above specification.

A systematic difference in RRR between FNAL and BNL was noticed in previous reviews. FNAL moved the argon inlet during coil heat treatment to the lead side. In coil 131, with the argon inlet in the RE side, the RRR was around 250. When the argon inlet was moved to the LE side, RRR is close to 400. CERN had similar observations in the past, and thanks to a series of improvements on the fixture tightness, the difference of RRR along the length was decrease. We recommend comparing the process. It should be noticed that with the samples only in the LE end, they will help to identify a RRR degradation due to a deviation on the temperature/duration of the different plateaus, but not a RRR degradation due to pollution in the system. If there are enough resources, one could install samples in both sides of the coils. Otherwise, it would be more conservative to have the samples on the argon outlet since the criteria is on the minimum required RRR for conductor stability, and the minimum is expected to be on the argon outlet side.

Cables are dimensionally within specification, but it was noticed some deviations on the cable mid-thickness. We recommend reviewing the cables that were produced in that period to identify if it is a single case or the process needs to be better controlled in terms of cable thickness.

In the absence of coil witness sample data, the analysis presented for coil ordering using the minor edge RRR of the extracted strands measured at LBNL and the rolled strand data from the supplier is deemed acceptable. There appear to be many options available for coil assembly for a voltage criterion of < 353 V.

Coils

For Coils the incidence of “popped” strands observed during coil winding needs to be addressed. This has been pointed out for previous coils. AUP is planning to have radiographic tomography performed on the failed coil (214) from MXAFA07. The committee strongly agrees with this approach.

Coil documentation should be uploaded to the CERN MTF system in a timely fashion. Today there is a substantial backlog since the coil information is not available for coils that have already been cold tested. By the time the magnet is tested, all information should be available. If coil DRs are uploaded to MTF before the coil review, it would be easier for reviewers to access to the documents (VPN or FNAL services account required to access vector).

Recommendations

None

3. Technical information

Committee
Steve Gourlay (chairperson), LBNL
Arup Ghosh, BNL retired
Susana Izquierdo Bermudez, CERN

Date and Time
September 8, 2021. Start time is 7/9/10/16 (LBNL/FNAL/BNL-FSU/CERN)

Location/Connection
Video-link by Zoom, info by email.

Link to agenda with talks and other documents
https://indico.fnal.gov/event/50739/

4. References

1) *MQXFA Functional Requirements Specification*, US-HiLumi-doc-36
2) *MQXFA09 Coils Acceptance Review Report*, US-HiLumi-doc-4091
3) *Specification for Quadrupole Magnet Conductor*, US-HiLumi-doc-40
4) *Cable Specification*, US-HiLumi-doc-74
5) *Quadrupole Magnet Cable Insulation*, US-HiLumi-doc-75
6) *QXFA Series Coil Production Specification*, US-HiLumi-doc-2986
7) *QXFA Series Coil Fabrication Electrical QC plan*, US-HiLumi-doc-521