US HL-LHC Accelerator Upgrade Project

Report of the MQXFA16 Coils Acceptance Review

July 11 2023

– Arup Ghosh (Chairperson), BNL retired
– Susana Izquierdo Bermudez, CERN
– Gianluca Sabbi, LBNL

TABLE OF CONTENTS

1. Goal and scope

The HL-LHC AUP project is planning to start assembly of MQXFA16. This is the 9th series low-beta quadrupole magnet (MQXFA) for the Inner Triplet of the High Luminosity LHC. If MQXFA16 meets MQXFA requirements [1] it will be used in a Q1/Q3 cryo-assembly to be installed in the HL-LHC.

For MQXFA16 assembly AUP is planning to use these QXFA coils (including two spare coils): 144,145, 234, 235 with 148 and 236 as spare coils.

Conductor and series coil specifications are presented in [2-6]. Discrepancy or Non-conformity Reports are generated whenever a component does not meet specifications. Magnet MQXFA16 is planned for use in Cold Mass 05 without previous vertical test. Therefore, the coils presented at this review were selected because they do not have critical Discrepancies/Non-conformities.

The reviewers are requested to review discrepancies and non-conformities in strands, cables, and coils for the following coils: 144 (cable P43OL1174), 145 (P43OL1179), 148 (P43OL1142), 234 (P43OL1176), 235 (P43OL1177) and 236 (P43OL1178).

Technical details

Committee

– Arup Ghosh (Chairperson), BNL retired
– Susana Izquierdo Bermudez, CERN
– Gianluca Sabbi, LBNL

Date and Time

July 11, 2023. 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/60405/

2. Review Charges responses

The committee is requested to answer the following questions:

1. Have all recommendations from previous reviews [7] been adequately addressed?

   Yes, as recommended Coil 220 was used instead of 109 for magnet MQXFA15.

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

   Strand and Cable: There were no critical DR's recorded for the cables in the six coils. For all the cables, during the sample heat-treatment, the TC's recorded at the 210C stage was higher than specification by a few degrees. This did not impact the RRR or the Ic of the strands as measured.
   The other DR's were all minor for the cables.

   Coil 144: Several DR's were recorded, none of which were critical. It is noted that during the HT of the coil, the 665C stage temperature profile recorded was abnormal. During the 665C hold a temperature excursion was noted during a manual change in set-point to achieve a tooling temperature of 665C. The HT was subsequently validated by measuring the witness samples.

   Coil 145 and 148: No significant DR's were recorded for these coils. All the non-critical DR's recorded have no impact on magnet performance.

   Coil 234: The only significant discrepancy is the coil length (4523.3 mm) which was smaller than the minimum specification of 4524 mm. BNL coils have tended to be at the lower range of the coil length specification of 4529 +/- 5 mm. The cause is not known. This was judged to be a non-critical DR as it should not impact coil performance.

   Coil 235 and 236: No significant DR's recorded for these coils.

   Coil Dimensions: There are no significant deviations in the dimensions measured at LBNL. None of the coils have any excess arc lengths. In fact, some of them are smaller than specs. As has been done for previous magnets, the coils will be shimmed on the mid-plane to compensate.
   Additional information was also provided regarding the arc length of the coils at the lead and return ends. Lately, there has been an interest in these dimensions to hypothesize an explanation for Coil 227 limiting the performance of magnet MQXFA13. Of the four coils in A13, Coil 227 had the lowest arc lengths at the ends. It is noted, that in the present set of coils being considered for A16 magnet, Coil 234 has the lowest arc lengths at the ends for all the coils tested to date.

Coil Ordering: Based on RRR measurements of rolled strands and minor edge RRR of extracted strands, there are many possible assembly options including the designated spares 148 and 236.

Overall, all DR's were properly recorded and adequately addressed.

3. Is there any critical Discrepancy/Non-conformity?

   No

4. Is there any coil that you recommend not to use in MQXFA16?

   Based on the cable and coil manufacture information, we do not reject any coil for use in the magnet. However, see below for our recommendation of the choice of the 4 coils for this magnet.

5. Do you have any other comment or recommendation regarding these coils and their conductor for allowing MQXFA16 to meet MQXFA requirements [1]?
   See sections below for comments and recommendations.

3. Comments

Recently a Working Group meeting was held to discuss on the analysis of MQXFA13 quench performance limitation. The main working hypothesis is that the issue is related to small coil ends resulting in lower radial friction between the coil and the structure. Measurements shows that coil 227 in magnet A13 has the smallest arc length in the ends. Mechanical analysis showed that in case a small arc length in the end regions is combined with pre-load at the lower boundary of the specification, the coil strain in the 'wedge/end-spacer transition' region can exceed the accepted limit of 0.3%

In order to maintain the coil strain below a safe limit, the pre-load can be increased toward the higher boundary of the specification. In addition, radial shimming or grading the loading key is being investigated as a way to compensate for smaller size in the ends. FE Model calculations are in progress for the different options. However, more time is required to analyze and implement a modified shimming scheme different than what has been used up to date for all the past magnets.

4. Recommendations

- Pending further analysis and assessment of the corrective actions for coil compensation at the ends, use coils 144, 145, 235 and 236 for magnet MQXFA16. The other two coils have smaller coil ends, so they can be designated as spares for the moment. There is no limitation to coil ordering if these coils are used.

- Currently, LBNL measures only two cross sections in the LE end (70 mm and 207 mm) and one in the RE end (4426 mm). In order to have a better picture of the coil size in the end region, it would be useful to measure one coil with higher longitudinal definition (one section every ≈ 50 mm). It will also help to improve the FE analysis if this information is fed into the model.

- Include the end regions in the coil dimensional requirements with a minimum threshold below which a critical discrepancy/non conformity would be triggered.

5. References

1) *MQXFA Functional Requirements Specification*, US-HiLumi-doc-36
2) *Review of MQXFA03 Coils and Shims*, US-HiLumi-doc-2180
3) *MQXFA10 Coils Acceptance Review*, US-HiLumi-doc-4186
4) *MQXFA12 Coils Acceptance Review*, US-HiLumi-doc-4321
5) *Specification for Quadrupole Magnet Conductor*, US-HiLumi-doc-40
6) *Cable Specification*, US-HiLumi-doc-74
7) *Quadrupole Magnet Cable Insulation*, US-HiLumi-doc-75
8) *QXFA Series Coil Production Specification*, US-HiLumi-doc-2986
9) *QXFA Series Coil Fabrication Electrical QC plan*, US-HiLumi-doc-521
10) *MQXFA14 Coils Acceptance Review*, US-HiLumi-doc-4769