US HL-LHC Accelerator Upgrade Project

Report of the Production Readiness Review of the HL-LHC AUP MQXF Cable Fabrication Task 302.2.03

January 22nd 2019

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1. Goal and scope

The HL-LHC Accelerator Upgrade Project (AUP) is planning to start MQXFA Cable Fabrication production
in February 2019. Cable fabrication is performed at LBNL, where all prototype and pre-series MQXF
cables were fabricated. Cable insulation, performed by external vendor, is included in the Cable
Fabrication task and in the scope of this review.
Production Readiness Review (PRR) is a major review step in the AUP. It is held prior to the start of
series production, and is intended to be a largely technical review, but include assessment of the
planned cost, schedule, and personnel needs to complete the production.
Scope of PRR:
- Parts and materials for cable fabrication and insulation
- Manufacturing and test procedures
- Interfaces
Goal of PRR:
- Approval of plans and procedures for cable fabrication task
- Validate plan to start manufacturing.

2. Technical details

Committee

Arup Ghosh (BNL, retired), chair
Bernardo Bordini (CERN)
Diego Perini (CERN)
GianLuca Sabbi (LBNL)

Date and Time

January 22, 2019

Location/Connection

LBNL, room 47-0114
Video-link by Zoom

Link to agenda with talks and other documents

https://indico.fnal.gov/event/19451/

3. Review Charges response

The committee is requested to answer the following questions:

1. Scope and interfaces: is the L3 task scope clearly defined and are interfaces with other tasks sufficiently well-defined for executing the series production?

A presentation was made by the AUP L3 cable task leader Dr Ian Pong (LBNL). We thank him for his presentation, and for all the appropriate documents that are relevant for the cabling task at LBNL. In addition, the follow-up material provided by him and Dr. Ambrosio were much appreciated.

Findings: The scope of the cabling task is clearly defined and so are the interfaces that govern interlab activities. However, the interface document may have to be modified if our recommendations in section 3 (QA/QC) are implemented

2. Manufacturing: are the manufacturing work flow documents and travelers — including scheduling, personnel needs, floor space, and facilities requirement— appropriate to execute the series production?

Findings: Manufacturing documents as shown are quite adequate and complete. Facilities identified in the presentation are adequate unless the backlog of unused strands becomes excessive. If for some reason, cabling is suspended for 2-3 months it is not clear whether there is adequate storage for strand that comprise 9-10 unit-lengths of cable.Travelers and work flow documents are complete. Cabling tasks and insulation task are well documented.

Recommendation: Ensure that there is enough storage facility for incoming strands from the wire manufacturer should there be an extended shut down of the cabling operation. It is possible that this storing can take place at a lab other than LBNL.

Personnel needs:

Finding: At present this task is being managed with two full-time trained technicians who are highly experienced. The task leader has stated that in production, 3 full time technicians are required. Although this level of support is sufficient during peak production, it is not clear how the peak production rate of 3 unit lengths/month can be managed if one of the technicians is absent for whatever reason. We note that there seems to be sufficient schedule contingency to mitigate this issue.

However, **we *recommend*** that this scenario be evaluated and, if necessary, have an action plan that can be implemented in such an event.

3. QA/QC: is the QA/QC plan adequate? Is there appropriate documentation for quality control procedures, manufacturing and inspection plan, and data reporting?

Findings: The plans to control work and perform QC tests are well defined. Work flow, manufacturing and inspection documents and data reporting plans are adequate. Using the present work planning, almost a dozen of cable unit lengths of type PO43 have been cabled and insulated. However, we have identified a few areas of concern one of which is due to the fact that in production the project may accumulate ~ 20 unit-lengths at FNAL awaiting coil winding. While that is a good scenario that removes this task from a critical path for coil winding, we feel that it also brings up the question of what if the cable has a problem that has not been identified after cable fabrication. In production the goal is to *deliver a product that is within specifications* and is *also fairly uniform in all properties.*

We note that at present, there are no plans to test the Ic of extracted strands after cable fabrication (sec 3.3.9 Doc 74). At present the plan is to test round and extracted strands that are reacted along with the coil. Round and extracted strand samples, representative of the strands in the cable, are sent to FNAL soon after cable fabrication. It was stated that, based on LARP and pre-production experience, it is sufficient to qualify the cable based on cable-edge damage assessment from metallographic examination of the cable x-section coupled with RRR measurements of extracted strands.

The committee is unanimous in that *there is a certain risk associated with not estimating the cable critical current using measurements of extracted strands after cable fabrication and waiting for such measurements after the cable has been used in a coil.* Since the backlog of cable in inventory can be as large of 20, any electrical problems associated with the cable unit lengths not being uniform from cabling run-to-run will not be readily detected.

We note that the RRR measurements of the minor edge at LBNL is indeed a good way to detect subelement damage. It would be fruitful if the minor-edge RRR measurements are correlated with IC measurements of extracted strand and with the degree of sub-element damage as observed in metallographic examination.

Along the same lines of a large backlog of cable during production, we also note that at present there is no test utilized to ensure that the cable is suitable for coil winding.

Recommendation 1: After cable fabrication, extracted strand samples should be shipped to a laboratory qualified for critical current measurements (via a benchmarking exercise). These samples should be mounted onto reaction barrels reacted using the prescribed HT schedule and then measured. These results are then to be used to qualify the cable critical current prior to coil winding. Since more than 75 % of the wire contained in a typical cable comes from 3 billets, in order to ensure the quality of the cable being produced, we recommend measuring the critical current of one extracted strand and of one adjacent round strand from each of the 3 billets representing at least 75 % of strands in the cable. To offset the additional (different from the present plan) testing cost and the burden on the test facility, we also recommend a modified approach to validating coil heat treatment1

Another possible option would be to test one pair (round and extracted) of strands per billet in the next several cables; use this information to better correlate the information from different tests (e.g. IC, RRR, sheared sub-elements) and establish the statistical controls, then drop the IC measurements to one pair per UL in later cables.

Recommendation 2: We urge the use of statistical process control tools to follow the production of cable in evaluating the uniformity of cable dimension, cable metallography examination, RRR, and cable or extracted strand critical current. This will allow detecting cables that are within spec but outside the norm of uniformity from cable to cable unit lengths. Examples of these are given at the end in the APPENDIX. Trending away from the norm should give pause to the cabling activity for evaluation of assignable cause(s).

Recommendation 3: We recommend introducing a form of bending test as a QC test to validate cable mechanical condition (section 7.3.6 doc 903, section 6.1 doc 74) for coil winding.

4. Cost and Schedule: are the cost and schedule estimates sufficiently well-defined and of adequate maturity to support the series production?

   Findings:
   Cost: Cost estimate is quite mature as this is an on-going work at LBNL for quite some time. The insulation task cost estimate is also good since LBNL now has a firm fixed price quotation from the industrial sub-contractor, NEWT.
   Schedule: With the planned coil production and strand delivery schedule, the cabling schedule is quite appropriate. It would appear that in peak production time, FNAL may have as much as 20 unit lengths in inventory pending coil winding. The schedule shows that the cable is not on any critical path.

5. ES&H: Have all hazards been identified and addressed? Are ES&H policy and documentation sufficient for the series production?

   Findings: LBNL has a good ES&H program. We find that there are no major hazards except the operation of the cabling machine and associated tasks. Personnel training is key. We note that the lab management is committed to make this task a success.

6. Risk: are risks understood and appropriately managed for the series production?

   Findings: Risk assessment is appropriate for this task. Management will rest on good machine maintenance practices which have been incorporated into the schedule.

   It is understood by this committee that in the event of a catastrophic machine breakdown it would necessitate temporarily moving production to CERN if the expected delay of repair is more that 4-6 months. This plan would require CERN approval.

7. Reviews: are all closeout recommendations for this L3 task from Final Design Review addressed?
   Yes

8. Is this L3 task ready for series production?

    A qualified yes. We recommend that additional QA/QC steps – as outlined in section 3 – are incorporated in the electrical and mechanical qualification of cable prior to coil winding. We are recommending upstream testing of IC after cable fabrication rather than downstream testing after coil reaction. So that the cost of the increased electrical testing is mitigated, we recommend that the electrical testing which is being done at the coil heat-treatment stage be modified[1].

    The recommendations outlined is section 3 would also require updating the cable specification document section 3.3.9 of the cable specification document "US_HL-LHCAUP_ Cable_Spec_Rev_B_Doc_74", and also other interface documents.

[1]For validating the heat treatment, it is sufficient to measure one or *two samples of round wire* taken from a *reference spool of wire* that is set aside for this purpose. The measurement of the witness sample is compared with a reference value expected for this wire. One possibility would be to include two of these samples in the reaction, and test one leaving the second as a backup. In addition, we suggest to add 4 extracted strand samples to the heat treatment and test one or more of them in the event that a problem is seen in the magnets.

4. Appendix

Fig 1. Using data provided we show the trend of the maximum % of sheared sub-elements observed at the minor edge for the first 12 production unit lengths. Note that the average is well below specification and the dotted line is the running average of 4 unit length of cable. A sudden increase above the upper control limit (UCL) should be a cause for concern even if it is less than 15%.

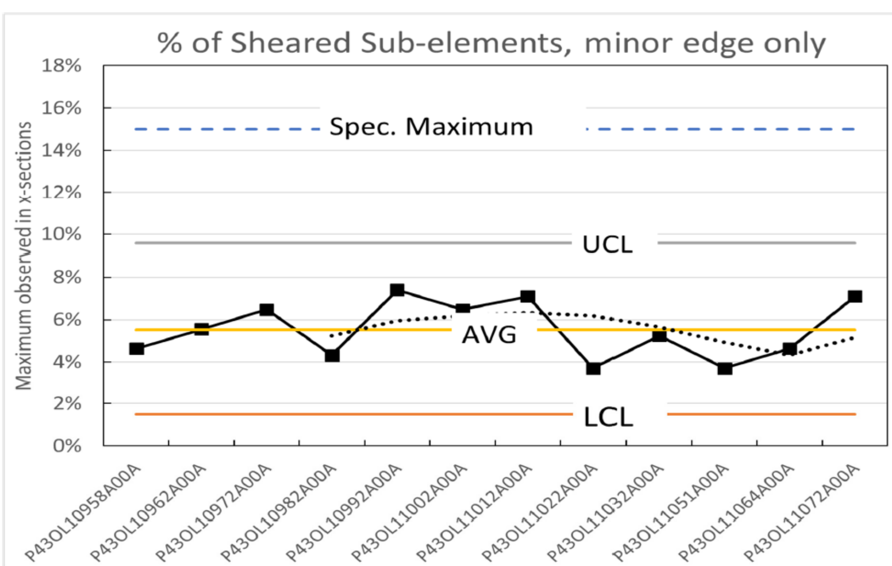

Fig. 2 Using the Ic of extracted strands from data provided, the average Ic at 12 T and 15 T of the extracted strands heat treated with a coil are plotted vs. coil ID.

Experience does indicate that cable Ic is well above minimum specification. If the cable Ic trends towards the lower control limit (LCL) established by the first 12 cables, it should be a cause for pause and evaluation. The dotted line is the 4-coil running average.