56th Meeting of the HL-LHC Technical Coordination Committee – 30/08/2018

Participants: C. Adorisio, A. Apollonio, G. Arduini, M. Bajko, A. Ballarino, B. Bordini, L. Bottura, H. Burkhardt, S. Claudet, R. De Maria, B. Delille, B. Di Girolamo, D. Delikaris, A. Devred. P. Ferracin, P. Fessia, M. Giovannozzi, S. Gilardoni, T. Lefevre, F. Mangiarotti, P. Martinez Urios, E. Metral, M. Modena, M. Pojer, S. Redaelli, F. Rodriguez Mateos, L. Rossi, F. Savary, E. Todesco, A. Verweij, S. Yammine, D. Wollmann, M. Zerlauth (chair).

Excused: O. Brüning, Y. Papaphilippou.

The slides of all presentations can be found on the website and Indico pages of the TCC.

M. Zerlauth recalled the actions from the 55th HL-LHC TCC. Concerning the estimate for the margins for the 11 T magnet to be given by L. Bottura, A. Devred mentioned that the proposal is to discuss the topic in the TE-TM, then in the TCC and finally in the LMC. J-M. Jimenez asked to review at the same time the assumptions on beam lifetime and the estimated losses in the DS. V. Mertens therefore put the presentation of L. Bottura in the TE-TM on hold. L. Rossi stressed that the presentation to the LMC should focus on the global ECR, discussions on such detailed technical points should take place in the TCC, hence the topic is rather urgent to be brought back.

P. Fessia presented in the 55th HL-LHC TCC an overview and mandate of the matching section optimization. M. Zerlauth encouraged the different WPs to provide feedback to P. Fessia if not yet done.

An update on the results of cold diode tests will be provided by TE-MPE at the end of the year, after the end of the presently ongoing measurement campaign in CHARM.

M. Zerlauth announced to the TCC that the first MD with crab cavities operating at 2 K was recently performed and congratulated the CRG colleagues for achieving this important milestone.

An update on the topic of beam screen vibrations should be given in the TCC after further elaboration by WP2, WP3, WP9 and WP12.

The minutes were approved.

11 T short model tests following review recommendations – F. Savary – slides

F. Savary acknowledged the work of many colleagues in the framework of the 11 T dipole task force.

F. Savary reminded the TCC about the 11 T dipole models constructed at CERN to date, from single aperture models to the most recent double aperture one (MBHSP107). The focus of the presentation will be on MBHSP107. MBHSP108 is in construction, tests are scheduled in October. L. Rossi asked if for MBHSP109 the coil is already available or a new one should be produced. F. Savary replied that they are going to reuse an existing coil.

The 11 T dipole task force was set-up at the end of 2017, addressing the limitations due to conductor degradation occurring during the collaring process due to excessive stress applied at the mid-plane of the coil. A new insulation scheme was implemented, allowing to reduce the total insulation thickness to 100 µm at 5 MPa thanks to new braiding conditions. The previous method never managed to respect the constraint of 100 µm thickness.

Test were carried out to characterize the irreversible degradation of the Nb_3Sn conductor due to transversal compression. The limit of 150 MPa was identified, which should not be exceeded during magnet assembly.

Measurements of coil stiffness, performed by applying pressure on the mid-plane and measuring the resulting stress, highlight variations from one coil to another.

F. Savary illustrated the improved tooling for collaring, lots of tests were performed for the collaring process. Measurements show the correlation between stress in the collar nose and stress in the coil mid-plane. This can be translated in a maximum acceptable excess in the length of the coil (300 µm) in order not to exceed 150 MPa.

F. Savary presented the results of the cold test of MBHSP107. The magnet required 3 quenches to reach nominal current and 10 quenches to reach ultimate. Holding tests were performed at both current levels. L. Rossi enquired about the location of the quenches in the coil and if any systematic effect was observed. It was pointed out that quenches occurred primarily in the inner layer, not always at the same place, both transversally and longitudinally. A. Devred stressed that the performance of this magnet model was conform to requirements so the tests were satisfactory, but further understanding is still possible. L. Rossi added that a high MIITs test could provide further insights. A. Devred explained that the risk of compromising the only model magnet conform to specifications should be evaluated before performing such kind of test.

The ongoing work is focusing on the collaring test on full length coils. Instrumentation will be put in place to monitor the process.

A. Verweij suggested considering to test the magnet with repetitive cycles to reproduce realistic LHC operation, e.g. by doing 50-100 cycles per day. L. Bottura commented that this was done in the past and no degradation was observed, but maybe it could be redone on model MBHSP108.

F. Rodriguez Mateos reminded the recent summary presented in the MCF for all electrical tests carried out on MQXF magnets and suggested repeating the same exercise for the 11 T dipole. L. Rossi agreed with the proposal.

Fine tuning of MQXF cross-section to optimize b6 – E. Todesco - slides

E. Todesco recalled the experience with the optimization of field quality for LHC magnets. Two iterations were required for MBs and one for MQs. One iteration was also required for LHC MQXFB. The optimization process led to a significant improvement in all the mentioned cases.

E. Todesco provided a summary of the measurements for MQXFS, giving an average b6 of around -4 to -6 units, versus a target of maximum one unit. Simulations from WP2, promptly done in early August after discussions within WP2 and WP3, highlight that with nominal b6 almost zero correction is required, while 100 % of the strength of correctors would be needed to correct for -6 units of b6. E. Todesco concluded that some measures need to be taken now in order to avoid consuming a large fraction of current in the according correctors.

L. Rossi asked if an understanding of this effect was already achieved, but this is not the case and possibly shall never be understood, as is the case of the corrections done in the LHC magnets.

E. Todesco explained that increasing b6 means decreasing midplane insulation or increasing the pole shim (or both). The proposal is to add 0.125 mm to the pole shim before winding and remove 0.125 mm on the midplane before impregnation. This shall shift up b6 by 5.3 units. The change only regards the straight part, there is no need for changing also the heads. If b6 shall be too high, a later reduction is possible through the insertion of additional insulation in the midplane during assembly. The proposed change shall be implemented in the MQXFBP2 (CERN) and in the MQXFA04 (HL-LHC AUP). The design change will be circulated before 15th September.

G. Arduini commented that this aspect was checked by WP2 (M. Giovannozzi and F. Van der Veken) and it was confirmed to be more critical in Q2, where there is the highest β.

DECISION: M. Zerlauth concluded that the TCC endorses the proposal concerning the measures to increase the b6 for MQXF.

Design decision on MQXF protection – E. Todesco - slides

E. Todesco reminded the TCC about the open points on the MQXF protection scheme. Since the beginning of the design, two options have been considered, featuring outer layer quench heaters and in addition inner layer quench heaters or CLIQ. The effectiveness of a redundant system with respect to outer layer quench heaters alone has been demonstrated, reducing the magnet hot spot temperature by about 100 K.

Both redundant protection options have been investigated and tested. CLIQ is a novel system,

which is not independent on the length of the magnet. CLIQ tests on several MQXF short models and on many other magnets including an LHC dipole proved that the system behaves as expected. First tests of CLIQ on a long MQXF magnet (MQXFAP1) were also in line with simulations. CLIQ was then tested on the MQXFS4 model in nominal configuration, also in this case the behavior was as expected.

Inner layer heaters were found to exhibit significant problems with delamination, bubbles are forming on the inner radius towards the beam screen. No shorts were produced due to this effect so far. Nevertheless it is deemed wise to remove the inner layer quench heaters from the baseline. The proposal is therefore to have outer layer quench heaters and CLIQ as protection baseline for the HL-LHC triplet.

L. Bottura pointed out that delamination was also observed in the 11 T magnet towards the pole, it might be a problem of adhesion of resin (impregnation) to metal. While he supports the removal of inner layer heaters from the triplet, the fundamental problem of delamination is still not understood.

L. Rossi recalled the initial idea to maintain inner layer quench heaters as a mitigation in case of failure of other protection mechanism. E. Todesco explained that the risk associated to inner layer heaters seems higher than the potential benefits at this point. A. Devred commented that he agrees with the proposal to remove inner layer heaters from the baseline, but also pointed out that no test of CLIQ in final configuration (final length, no energy extraction) has been done. E. Todesco confirmed that the validation of CLIQ in nominal configuration will continue in 2018 and 2019 with US and CERN prototype. It is also pointed out that the final validation of CLIQ with the complexity of the 18 kA circuit will be possible only in the STRING, and it is one of its main motivations. Nevertheless, today we can state that no showstoppers are visible in the adoption of outer layer heaters and CLIQ as baseline.

F. Rodriguez Mateos commented that the long term stability should be explored; this is foreseen in the plan for short models. MPE is fully in favor of performing additional extensive testing of CLIQ, also for this purpose 3 CLIQ units are already available and five more will be manufactured. Also the development of CLIQ units is ongoing, the final version will be available for the STRING tests.

L. Rossi asked if intra-layer quench heaters are still being considered as a possibility nowadays. L. Bottura explained that they were tested and proven to work, but they were not more effective than inner or outer layer heaters, so they are no longer pursued.

Non conformity of the PIT cable: impact on magnet margin – B. Bordini - slides

B. Bordini recalled the limitations in terms of the RRR of the stabilizing copper of the regular PIT wire, which did not allow to meet the specifications for the HL-LHC MQXF magnet. CERN successfully developed an alternative design, the bundle barrier PIT, which allowed overcoming the problems with the previous version of the wire. The bundle barrier PIT features a common Nb diffusion barrier separating the filaments from the outer copper, and

has a larger percentage of Tin in the filaments and adopts a more aggressive heat treatment. These changes made the wire conform to HL specifications and allowed reducing initial costs.

The drawback of the bundle barrier PIT is a slightly larger degradation of the critical current during cabling, as the design is more sensitive to mechanical deformation. This effect was discovered during the development and is explained by the fact that during heat treatment the Nb_3Sn front has a higher probability of reaching the copper stabilizer. A. Devred commented that in industry Tantalum barriers are used to counteract this effect. B. Bordini explained that this was considered during the development, but it was not possible to achieve the required thickness for this layer.

B. Bordini recalled the specifications for the acceptable critical current degradation during cabling (5 % degradation and RRR of the copper stabilizer larger than 100). A. Devred pointed out that the cable specifications should be formalized in a document. A. Ballarino explained that a document exists where the acceptance criteria for the cable in terms of critical current degradation is specified (5 % accepted). L. Rossi asked if this is the same criteria that are adopted by the US collaborators, A. Ballarino confirmed this is the case. A. Devred commented that in addition, a specification documents covering the transition from the cable production to magnet production should be prepared.

Three long cables were produced using the bundle barrier PIT, showing an average critical current degradation of 7-8 %, signifying that with present specifications the PIT cable would not be conform for HL-LHC. Nevertheless, this criterion was set considering the behavior of the RRP wire, for which cabling has a high impact on the RRR. A critical current degradation of 10 % for the PIT conductor has a limited impact on the magnet margin and the cabling process has a limited impact on RRR of the bundle barrier PIT. It is therefore proposed to increase the average degradation limit of the bundle barrier PIT cable to 10 %, while keeping the 5 % for the RRP cable.

L. Rossi asked if PIT wires were ever rejected in the past due to the non-conformity with respect to performance degradation due to mechanical deformations. B. Bordini explained that so far it was never the case; for the R&D contracts and for the first contract of the final HL-LHC PIT wire to be used in the prototype MQXF magnet, the electrical acceptance criteria were based on wire samples that experienced a limited mechanical deformation (10% reduction of the height). This level of deformation has practically no impact on the wire performance. A more stringent acceptance criterion (15% reduction of the height) was introduced for the wire of the series magnets; in this case all the measurements from the supplier still satisfy the HL-LHC specification while some measurements from CERN show a not conform performance for some billets; studies are ongoing for understanding this discrepancy between CERN and supplier data.

E. Todesco stated that from the magnet point of view the proposal is acceptable, as enough margin is available. A. Devred pointed out that specifications should be respected, as in production there could be further degradation.

ACTION: MSC should report in the TCC on the outcome of the discussions concerning documentation for cable acceptance criteria.

Powering of Q5 in IR6 to ultimate current – M. Pojer - slides

M. Pojer reported the results concerning the powering of Q5 in IR6 to ultimate current for HL-LHC. The test aimed at assessing if requirements imposed by ATS optics for HL-LHC for these magnets would be achievable with the present hardware. RQ5.L6 was successfully powered beyond the layout ultimate current (4000 A vs 3900 A) during the YETS17/18, with a limited number of quenches. From the tests performed, powering to 7 TeV seems to be feasible without any hardware upgrade. To operate at 7.5 TeV though, currents would exceed 4000 A, which does not leave much space for stable and reliable operation of Q5.L6, especially considering losses during dumps. From the hardware point of view, the limitation for currents above 4000 A could potentially come from the DCCTs, but changing DCCTs is not expected to be a major problem if necessary. For Q5.R6, operation at 7.5 TeV should be possible without any upgrade, but this will have to be confirmed by a dedicated test during the end of run powering tests, as confirmed by R. De Maria.

L. Rossi concluded that from the analysis for HL-LHC in Run 4 (at 7 TeV) there will be no need for hardware modifications.

The presentation by P. Fessia on the status of drawings to document ECRs was postponed to one of the next TCC meetings.