4th Meeting of the HL-LHC Technical Coordination Committee

Participants: A. Apollonio, G. Arduini, B. Auchmann, V. Baglin, A. Ballarino, I. Bejar Alonso, S. Bertolasi, J.P. Burnet, R. Calaga, O. Capatina, S. Claudet, B. Di Girolamo, P. Fessia, P. Ferracin, M. Giovannozzi, H. Mainaud Durand, M. Martino, T. Otto, Y. Papaphilippou, V. Parma, M. Pojer, D. Ramos, S. Redaelli, F. Rodriguez Mateos, L. Rossi, J.P. Tock, E. Todesco, R. Tomas, R. Van Weelderen, D. Wollmann, M. Zerlauth.

Excused: L. Bottura, C. Bracco, O. Brüning, R. Jones, J. Jowett.

The slides of all presentations can be found on the website and Indico pages of the PLC:

HL-LHC PLC/TC homepage: https://espace.cern.ch/HiLumi/TCC/Default/Home.aspx

Indico link: https://indico.cern.ch/event/476960/

M. Zerlauth recalled the actions from the previous HL-TCC.

On the possibility of pushing the MQY gradient to 180 T/m (beyond ultimate, requiring a current of >4 kA), it was confirmed that this is not feasible presently, as limitations are imposed by the installed power converter (maximum current 4 kA) and DCCTs. Hence the request for a test during this years HWC campaign was removed from the minutes (and MP3 and HWC coordination informed). The final confirmation from WP2 on the possibility to keep the left Q5 magnet at 4.5 K, requires inputs from WP14 on the assumption for the beam size at the protection elements, which will be available by June. E. Todesco pointed out that in any case pushing a magnet beyond ultimate entails high risks. L. Rossi clarified that for the possible tests at the end of December 2016, the interest would nevertheless be to go to ultimate current (3.9 kA).

Concerning the readiness of SM18 for the preparation of CC cryomodule tests, L. Rossi reported from a dedicated meeting this morning, aiming at finding additional margins for the preparation and commissioning of the cc module with respect to the current schedule.

Operating temperature of Q6 in P1/P5, S. Claudet, M. Giovannozzi - slides1, slides2)

S. Claudet recalled the discussion on the operating temperature of Q6 magnets in P1/P5. Following an action from the 2nd HL-TCC, the 1.9 K and 4.5 K options remained to be evaluated in terms optics requirements, costs, and operability (commissioning, maintainability,…).

S. Claudet reminded about the current baseline for the cryogenic system: inner triplets, D1, D2, Q4 magnets will be operated at 1.9 K, with pressurized helium, the crab cavities at 1.9 K with saturated helium. From the 32nd HL-TC meeting, the decision was taken to have magnets from Q1 to D1 at 1.9 K, with the beam screen at 40-60 K (or equivalent) and magnets from D2 to Q5 at 1.9 K with the beam screen at 4.5-20 K. Only the temperature of Q6 remained to be confirmed. Serge pointed out that documents were found from 2014 quoting an operating temperature of Q6 of 4.5 K.

M. Zerlauth commented that in PDR the Q6 is consistently mentioned at 1.9 K operating temperature. In the TDR, in the magnet and cryogenic sections, the Q6 is considered at 1.9 K (with an option to leave it to 4.5 K to be studied), whereas in the machine layout it is mentioned being at 4.5 K. L. Rossi confirmed that the baseline has always been 1.9 K and recommended correcting the inconsistencies in the TDR.

S. Claudet explained that the cooling principle in case of 1.9 K temperature is based on conduction cooling, which is already being developed, therefore having Q6 at 1.9 K wouldn't require additional developments from the cryogenic point of view.

From the point of view of capital costs, S. Claudet stated that there's no big difference expected between the two options (possibly 4x25 kCHF more for 1.9 K). Concerning operational costs, the 1.9 K requires additional 200 kCHF over 10 years (for 4 magnets).

The 1.9 K option would however ensure easier commissioning and helium management for the cryogenic group.

S. Claudet concluded that from the cryogenic point of view there's a slight preference for the 1.9 K option, but that no showstoppers are expected for 4.5 K.

M. Giovannozzi presented the Q6 magnet strength requirements from the optics perspective. The Q6 requires large currents for large β* and low currents for low β*. Given that the highest β* optics in the HL-LHC era will be 30 m for VdM scans, M. Giovannozzi concluded that there's no need for a Q6 gradient higher that 160 T/m in IR1/5. P. Fessia pointed out that some limitations could appear during the squeeze, due to required current ramp rate. M. Giovannozzi explained that with β* levelling, constraints on the squeeze will be relaxed. G. Arduini pointed out that for levelling at $7.5*10^{34}$ for ultimate HL-LHC the situation should be evaluated. M. Zerlauth commented that limitations for the ramp-down case are imposed by the power converter (due to the current unipolar converter type).

From the magnet point of view, M. Zerlauth recalled the cost estimate provided by H. Prin for Q5 in P6, as the required effort for Q6 in P1/5 is deemed comparable for the two cases. The order of costs associated with the 1.9 K option for the Q6 magnet is 700-800 kCHF for 4 assemblies (plus the cost for manpower). P. Fessia pointed out that the actual cost for modifications amounts to 350 kCHF per pair of magnets (as announced fro Q5 in IR6), as there's no need for a new cryostat.

L. Rossi summarized the discussion and the cost/benefit associated to the two options: there's no strong preference for the 1.9 K options for optics, but to allow for operational flexibility and to ease the commissioning it would be preferred by the project to remain with the current baseline (1.9 K), at an additional cost of 700-800 kCHF. This also implies a possible gain in availability. E. Todesco pointed out that amount of costs is non negligible and the choice of 1.9 K implies additional workload on WP3, thus he recommended informing as well L. Bottura of this decision.

R. Van Weelderen asked if higher heat loads due to electron-cloud have to be expected on the Q6 magnet. G. Arduini commented that a table with values of heat load for all insertion region magnets was provided by WP2. R. Van Weelderen replied that based on the values provided, no limitations are expected.

State of discussions in preparation for the circuit review (F. Rodriguez Mateos - slides)

F. Rodriguez Mateos presented the status of the discussions in preparation for the HL circuit review, which will be held at CERN on 21st to 23rd March 2016.

An overview on the ongoing studies being carried out on the electrical circuits will be given in the review, in terms of protection, compatibility and integration, dependability and costs. The criterion for magnet protection has been set to a maximum peak hot-spot temperature of 350 K and a maximum voltage to ground of 1.5 kV.

Points for discussion during the review are the adopted number of circuits, the achievable ramp rate for the ramp-down (which has implications on power converters and losses in passive elements) and circuit protection. The definition of a protection strategy requires the assumption of a number of parameters (e.g. number of quench heater strips used and kept as spares, internal redundancy of CLIQ units, presence of bypass elements,...).

E. Todesco pointed out that all options should be denominated 'proposals for an update' of the current baseline, rather than a 'new' baseline.

The two main alternatives with respect to the current baseline which are going to be discussed concern the inner triplet circuit and the D1/D2 circuits.

The baseline for inner triplets foresees two main 1-quadrant power converters and 2 trim power converters (option 1). The slow discharge is a free-wheel discharge in this case.

A possible alternative is to adopt one main 2-quadrant power converter and 3 trim power converters (option 2). The slow discharge would be achieved with the 2-quadrant power converter. The protection is based on a combination of quench heaters and CLIQ units. Parallel elements allow reducing voltages to ground. Warm bypass diodes should be used to mitigate potential high radiation doses. All parallel elements can be installed on the leads already used for the trim power converters. For protection, the polarity of CLIQ units and quench heaters plays an important role (e.g. higher coil to heater voltage could be produced in case of wrong polarity).

B. Auchmann pointed out that all trim leads should be designed for 2 kA, also due to the presence of CLIQ protection. An effort must be made for optimization of the leads topology. A. Ballarino asked if CLIQ leads would be part of the SC link, F. Rodriguez Mateos explained that this is not the case, CLIQ leads are warm leads.

F. Rodriguez Mateos illustrated the proposed quench heater connection scheme, including both inner layer and outer layer quench heaters. The inner layer quench heaters would in this configuration, already featuring the CLIQ protection, be kept as back-up protection (not connected by default but only e.g. in case of failures of outer HF heaters).

Failure cases for different protection configurations have to be evaluated. A worst-case failure analysis has been carried out for option 2. Non-realistic failures (i.e. failures for which the probability of occurrence is deemed extremely low, e.g. combined failures) were not included in the analysis. Reference values for design of protection systems were presented in slide 20. The peak hot-spot temperature reached for option 2 is 305 K. P. Ferracin confirmed that also in case of a CLIQ failure (i.e. exclusive use of high-field heaters) the peak hot-spot temperature would remain below 350 K. E. Todesco asked why inner layer quench heaters are not being considered as part of the protection strategy, as reaching 350 K would be just at the limit of the tolerances. F. Rodriguez Matos clarified that inner layer quench heaters would still be installed, but would just not be used by default during operation. E. Todesco stated that it seems premature to change the strategy already, the final choice will depend on experience gained with the different systems, e.g. at the moment it is not clear if stress levels caused by the use of CLIQ would be better or worse than those of inner layer quench heaters. F. Rodriguez Mateos pointed out that having full redundancy (outer quench heaters + inner quench heaters + CLIQ) would imply having 10/12 quench heater power supplies per magnet, which doesn't seem optimal for both integration and availability. L. Rossi asked if there's space reserved for inner layer QH power supplies. P. Fessia confirmed this space was allocated following a request from D. Wollmann. P. Ferracin confirmed that the outcome of the workshop on IT was indeed to have inner layer quench heaters as backup protection (not in operation). L. Rossi agreed that both CLIQ and inner layer quench heaters have to be tested and validated before taking a decision, G. Ambrosio will have a presentation on IT protection in the circuit review.

For the D1-D2 circuits the baseline foresees two independent circuits. The alternative option is to move to a single-circuit configuration. Changes in the current proposal would be required only on the warm side of the circuit. Powering via a 2-quadrant power converter (already developed for ITs) would bring a substantial saving. This option would nevertheless require the deployment of a warm bridge, to be done close to the power converter to avoid a large inductive loops. A. Ballarino commented that the warm bridge could be potentially quite short. P. Fessia stated that it would be in the order of 40 m and that the layout has been fixed, so there's no possibility for major changes. L. Rossi asked if this option would be convenient for optics. G. Arduini confirmed that this would reduce the sensitivity to ripple of the power converters and it would reduce the number of high current power converters, but a small trim power converter would be required to compensate for the different transfer functions. J.P Burnet stated that no trim is currently foreseen in this option and that cost saving should be evaluated also considering the increased complexity (warm bridge + 2 sets of diodes + more than double number of water cooling cables) and possibly longer commissioning time. S. Claudet pointed out that D2 is from the cryogenic point of view part of the matching section, while the D1 is part of the inner triplet subsector, therefore D1 and D2 would only be in series from the electrical point of view in this option but in 2 different cryogenic environments. This could have implications on tests and commissioning.

Concerning the protection of D1 and D2, the proposal is to use redundant quench heaters (same configuration as dipoles today) and to only install CLIQ leads for connection in case of loss of redundancy on quench heaters. D. Wollmann recommended converging on a limited number of options for protection, as performing circuit protection simulations for each case is very time consuming.

P. Fessia introduced the idea to study powering in series the two apertures of Q4-Q5-Q6 magnets, as the maximum current difference in the circuits is limited, e.g. by considering a double circuit consisting of a main power converter plus a trim power converter. This would allow reducing the number of leads on the link and the number of splices and saving space, affecting potentially a total of 12 circuits. This option should be studied from the optics point of view.

A. Ballarino asked if Q5 and Q6 will keep the same number of leads as today. Presently the assumption for Q4 is to have 4 leads, ensuring the highest flexibility. M. Giovannozzi commented that the current optics is being designed on the assumption of having only 3 leads (present case) with the possibility to operate with a single power converter powering in series the two apertures and trim power converter to unbalance them taking into account that large asymmetries in the powering of the two apertures could anyway result in poorer field quality. The Q4 magnet has a high impact on the dynamic aperture.

ACTION: The feasibility of powering the two apertures of Q4-Q5-Q6 in series should be investigated, starting with recommendations from WP2.

L. Rossi summarized the discussion on the circuit. For the IT, there's a general consensus on the advantage of going to one main 2-quadrant power supply plus 3 trim power supplies. For D1/D2, more discussions are still needed.

ACTION: A. Ballarino requested to receive updated assumptions for circuit time constants (WP7).

Triplet workshop highlights (P. Ferracin - slides)

P. Ferracin presented a summary of the MQXF workshop, held at CERN from 2nd February to 4th February 2016.

Day 1 of the workshop focused on the analysis of mechanical performance of short models with dummy and real coils and on the review of the assembly process of the short model. A comparison of stress levels measured by CERN and LARP with different strain gauge configurations was presented. A good agreement was found amongst the measurements (within 10 MPa). The conclusion was to try converging to the CERN system, as it's the easiest to install.

Day 2 focused on prototype design and assembly and alignment. Following the discussions on alignment, a follow-up meeting will be organized between WP2 and WP3. Concerning the options of having the bus bar 'in' or 'out', a final decision was not taken, but a preference was expressed to have it 'out'.

Day 3 focused on the triplet circuit and protection. As already mentioned during the meeting, the proposal to have outer quench heaters and CLIQ (with inner quench heaters as backup) was accepted. L. Rossi asked if tests on CLIQ units were carried out on the short model in the US. F. Rodriguez Mateos confirmed this was not the case and that the program does not foresee them to happen before the circuit review. L. Rossi stated it would have been interesting to have some results in view of the LARP meeting in May.

P. Ferracin reported on the MQXFS01 test at FNAL in terms of quench performance, mechanical behaviour, field quality and quench protection.

During the magnet training, the first quench was observed at 66% of the nominal current and the nominal gradient was reached after 7 quenches (slow start). All coils were tested, coil 103 proved to be the weakest and quenches were localized in high field areas, as expected.

The analysis of the mechanical performance revealed that the magnet was not heavily pre-stressed, which can be an explanation for slower training. This relationship was proven in the past on magnet HQ02, showing that increasing the pre-load made the training faster.

L. Rossi commented that these tests were a great success and that he favours a start with lower pre-stress for safety reasons. L. Rossi added that given the good results of individual tests, it is now time to focus on the integration of the individual components in the electrical circuits.

P. Fessia reminded that the current baseline is to have BLMs on the cold mass working at cryogenic temperature, installed in the 1.9 K bath. The integration of such system is not trivial. ACTION: an update from BI (R. Jones, B. Dehning) on the plans for BLMs in the triplet should be presented in one of the next HL-TCC meetings.

AOB

M. Zerlauth announced that the meeting scheduled on 17th March was cancelled and recalled the topics for the next meetings.

An update on the simulations and measurements of RF fingers in the triplet region will be presented in one of the next HL-TCC meetings.

F. Cerutti will present the latest FLUKA studies in the triplet region (as input to the discussion on required shielding of BPMs).

ACTION G. Arduini proposed revising the beam screen/cold bore tolerances for the triplets and in general the impact on the available aperture