40th Meeting of the HL-LHC Technical Coordination Committee – 02/11/2017

Participants: G. Arduini, V. Baglin, A. Ballarino, D. Berkowitz, L. Bottura, O. Brüning (chair), J. P. Burnet, S. Claudet, D. Delikaris, P. Fessia, L. Fiscarelli, G. Iadarola, S. Izquierdo Bermudez, Y. Leclercq, M. Martino, F. Menendez Camara, E. Metral, M. Modena, E. Monneret, Y. Papaphilippou, A. Perin, M. Pojer, S. Redaelli, F. Rodriguez Mateos, L. Rossi, F. Savary, M. Sisti, L. Tavian, E. Todesco, R. Vennes, R. Van Welderen, D. Wollmann, S. Yammine.

Excused: A. Apollonio, M. Zerlauth.

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

The minutes of the 39th HL-LHC TCC were approved without further comments. There was only one action regarding the follow-up of the D1 protection with respect to magnet quenches. The agenda of the present meeting is reviewed.

Changes to the superconducting circuits baseline, F. Rodriguez Mateos - slides

F. Rodriguez Mateos gives a status report on the super-conducting (SC) circuits following the review of March 2017. Since the review, several meetings took place to progress on the recommendations and actions. A detailed table of follow-ups is being presented, differentiating the options that are not adopted with respect to the ones that decision is pending. The open issues are marked with a class of uncertainty, from 1 for advanced to 5 for "just starting". Following the question of O. Brüning if all these items are part of the baseline, F. Rodriguez Mateos clarifies that these are recommendations from the review. Regarding the Q1a trim for k-modulation, he explains that it was already baseline and was endorsed by the review, but the circuit definition is not yet finalized.

A list of the main subjects for Inner Triplet (IT) is provided. A. Ballarino will be covering the local powering part during this meeting. Some conclusions from simulations are presented, leading to the decision for the trim leads/link/bus bars of a 7 kA current capability and 5 MIITs load to have margin. There were detailed simulations covering the whole parameter spectrum from low to ultimate current, done by E. Ravaiolli at LBNL. They were further benchmarked by M. Mentink using a different code (STEAM-LEDET with respect to TALES previously used), with the same conclusions.

Regarding the Q1a trim for k-modulation, it was first thought that a high ohmic impedance circuit would be adequate and limit maximum currents conveniently. Some further work by

MCF and WP6b, was done in particular intending to use an existing type of power supply. The present proposal corresponds to a copper cable with section of 20 mm2 and maximum current of 4.2 kA and MIITs of 1.66. L. Rossi remarks that this circuit inclusion, although it was thought by the Review Panel Members to be simple and straight forward, turned out to be a quite serious one, as reflected by the cable cross section and the high MIITs. F. Rodriguez Mateos replies that during the Review, it was indeed thought that a 10 mm2 cable would be sufficient but this is finally not the case. Additional diodes (one for Q1a and one for Q1b) could solve the problem but this requires further analysis. He further clarifies, following a question by A. Ballarino, that these 35 A are local leads and not connected to the SC link, the same as it happens for the CLIQ leads. O. Brüning stresses that this trim is required for k-modulation optics measurement with very low intensity beam and not used for routine operation, as also explained by G. Arduini. F. Rodriguez Mateos points out though that this does not change anything with respect to the circuit specifications and the quench protection point of view. In this respect, G. Arduini proposes to have the wire disconnected after the measurements and M. Pojer reiterates that from the circuit failure point of view, this does not change the picture either. P. Fessia stresses that these cables come from an area which is one of the most radioactive of the machine with severe space constraints. L. Rossi suggests that a special meeting is organized under the lead of WP3, together with MCF, integration, cryogenics, WP6a and WP6b for optimizing the integration of this circuit, as minimizing radiation is a must. He further suggests to study a circuit with a resistance which is twice higher and a current that is halved, in order to understand the implications. Although it was mentioned that the response of the inner triplets is by far not linear, some optimization may be possible.

ACTION (lead by WP3): The Q1a k-modulation trim integration should be optimized taking into account the impact of radiation and space constraints in the IT area.

ACTION (MCF): Further studies of the Q1a k-modulation circuit should be undertaken in order to find an optimum, targeting the reduction of the present cable cross section and maximum MIITs.

F. Rodriguez Mateos proceeds with explaining the cold diode option for the inner triplets. L. Rossi points out that as the diodes' robustness vs radiation damage and fluences is not yet proven, they cannot be considered as a baseline. F. Rodriguez Mateos adds that indeed the circuit without diode was considered "robust" during the review.

Regarding the overall strategy for protection when including cold diodes, two sub-options exist. According to the first sub-option, all Quench Heaters (QH) and CLIQ systems are fired in the case of quench anywhere in the circuit, with diodes carrying only the over-currents below 7 kA. In the other option, a selective firing of QHs and CLIQ is done, this implying that diodes would carry 18 kA with a much longer time constant. A. Ballarino mentions that using 7 kA diodes will not reduce the danger to the circuit (for that, diodes dimensioned for full current shall be integrated). F. Rodriguez Mateos adds that the present LHC diodes, if they are qualified for the required radiation level, they will be the adequate solution (without scaling for the different current density). The second sub-option is more difficult to integrate and will need a completely new diode technology (larger wafers), as also confirmed by the manufacturer (Dynex). L. Rossi asks if there is the possibility to reduce the time constant from

100 to 50 s, for example. F. Rodriguez Mateos replies that this would increase the voltage required at the converter's crow bar. WP6b has already stated that 50 V is the maximum the present converter technology can accept. L. Rossi further questions the fact that by quenching one magnet, all QHs and CLIQ fire and F. Rodriguez Mateos answers that forced quench of SC link is not required in case of a magnet quench, as also confirmed by A. Ballarino.

The QPS strategy is further detailed with the schematics of the two sub-options within the cold diode option, and the logic behind the choice of option one for which all QPS systems are fired when any element of the circuit is quenching. The selective quench strategy of the second sub-option could have only worked if the quench detection works separately for magnets and bus-bars, but this is not presently possible. In the question of A. Ballarino if the cold diode is limited to 7 kA, F. Rodriguez Mateos replies that most diodes carry up to 30 kA but for single shot, non-repetitive surge current. Following a question with respect to the interest on limiting diodes at 7 kA, L. Rossi answers that this is required for using LHC diodes. L. Bottura comments that this option (limiting the diodes to 7 kA) is indeed inadequate for selective quenching. F. Rodriguez Mateos underlines that 7 kA is not a hard limit for a diode like the ones from LHC at present (see above). After the question of F. Rodriguez Mateos regarding the endorsement of the choice by the TCC, O. Brüning concludes that there is indeed agreement from all experts.

ACTION (MCF): The TCC endorses the choice of the QPS strategy, for which, when one element quenches, all QPS systems are fired.

F. Rodriguez Mateos proceeds on detailing the proposal for the circuit separator for IT magnets. A combined task force was formed with participation of WP6a and WP6b for the integration of separators in cabinets and the work is in progress. L. Rossi asks if the integration is adequate, and P. Fessia answers that this is an option where further work is needed for reaching a conclusion.

A progress report on the cold diode project is given, including FLUKA simulations for the heat load and preparation for experimental irradiation tests of diodes at the CHARM facility in a cryocooler. F. Rodriguez Mateos finishes his presentation by flushing a slide with documents triggered by WP6a and MCF and skipping the part on IT correctors and the 11 T dipole trim, as they will be covered by A. Ballarino's presentations. He concludes by stating that the progress is quite good and a draft ECR document is being prepared with all the changes. O. Brüning thanks F. Rodriguez Mateos for all the work done and progress and concludes that there are several points to be followed-up before converging and documenting all the final decisions into the ECR.

Discussion

G. Arduini would like to re-iterate the question on the possibility of a higher resistance (smaller cross section) of the current lead for the Q1a trim. F. Rodriguez Mateos explains that the issue is the overcurrent in copper, especially in the conservative case with high quenching unbalance between Q1a and Q1b. G. Arduini asks if it would be possible to have higher impedance and connect two power converters in series and repeated that this trim is needed only during commissioning and not during operation. Some doubts were raised by L. Rossi and

M. Pojer regarding availability and O. Brüning concludes that contrary to what was originally thought, more studies are needed for the k-modulation trim.

Powering of 11 T trim, A. Ballarino, - slides

A. Ballarino introduces the subject, regarding the recommendation of the circuit review to consider a trim in order to compensate the difference in the transfer function (TF) of the 11 T dipoles with respect to the main ones. The design of the gas leads was pursued by cryostat team and the idea was to study gas-cooled leads able to withstand a voltage of 3.1 kV. In October 2017, a decision was taken to use conduction-cooled leads of the LHC-type, and the project was taken over by SCD. A reminder is given of the LHC design, including the details on the thermalisation concept. The key challenge is their operation on the main vacuum insulation of the cryostat.

The work performed since last October include the review of the integration study, physically enabling to use the same design (components and size). A schematic is presented, showing the leads inside the 11 T cryostat, proving that the same integration strategy can be adopted.

A number of electrical insulation tests were performed on LHC conduction-cooled 120 A leads. It was further proposed and discussed/agreed with EPC to use two current leads per polarity, forming one assembly of four leads per circuit as in the LHC. A consensus was found for the protection of the leads in case of a voltage excess with threshold of about 100 mV and detection of unequal current. A slide with the protection concept is presented which is pending some verification of the routing of the cables and is followed up by WP6b. Finally, in view of the very short time available for designing and constructing the leads (requested for integration in June 2018), a tentative success oriented schedule is presented, with roughly 6 months left. In this respect, support is needed from the main workshop and designer office.

Discussion

E. Todesco enquires if this solution is the adopted one for the correctors too, and A. Ballarino answers positively. After a remark by L. Rossi regarding the consideration of gas-cooled leads, A. Ballarino clarifies that the study was indeed done by the CMI team but a decision finally was taken to choose conduction cooling leads and the project was passed to SCD in October 2017. S. Claudet adds that gas cooled leads are much more delicate and he fully supports this decision. M. Pojer enquires if 4 % of the current is really needed. A. Ballarino explains that this is an additional safety for current unbalances, in particular in case that cables are not properly connected, and reliability is indeed ensured. J.- P. Burnet adds that an interlock at 120 A for the maximum current for one cable could solve the problem.

Local integration of the 120A and 200A circuits inside the magnet cryostat, A. Ballarino - slides

After showing a table with the circuit proposed for local powering, A. Ballarino explains the main advantages of the choice, namely simplified cabling of the SC link, simplified plugs and leads, elimination of the splices in DFX and DFH and no need for developing gas cooled leads and the additional supporting and control equipment. A schematic of a preliminary integration study is shown, with five current lead assemblies fitted in the corrector package. They are conduction cooled with a geometry to be defined. A list of items to be studied is presented, including routing possibilities of RT cables, local integration and the refined design of LHC type conduction cooled leads. Other alternatives are looked at but cryostat design is not well advanced. They are no evident show-stoppers but verifications are necessary. Regarding the trim of Q1a (k-modulation), it is presently considered as part of the local instrumentation (as CLIQ) and not part of the cold powering system. In the question of L. Bottura whether the gain of simplification has also a cost impact, A. Ballarino answers certainly yes, and that this should be further assessed.

Discussion

L. Tavian mentions that the impact on cooling and ventilation should be verified as there will be additional heating. A. Ballarino answers that this was indeed already pointed out by P. Fessia and will be looked into in more detail. P. Fessia explains that presently space has not yet been allocated, and a solution has to be found for a cable fixed point for remote alignment. The cooling of the cable has to be checked as its vertical course is close to a chimney capturing the heat. Issues with radioprotection (as pointed also by L. Tavian), electrical integrity (ELQA) and the change of cryostat design should be also addressed. L. Rossi concludes that the proposal is to have as baseline 120 A conduction cooled leads. O. Brüning takes note of the proposal and suggests to return to the TCC after a detailed study.

ACTION (WP6a): The TCC takes note of the proposal for the 120 A conduction cooled leads for the local powering of the IT correctors and WP6a should present the details of the design in a future meeting and document the change with an ECR (action WP6a leader)

Decision for the necessity of testing the DFX, A. Ballarino

A. Ballarino states that there is consensus not to test each individual DFX, as also agreed with V. Parma.

Beam induced heat loads on HL-LHC Beam Screens, G. Iadarola- slides

G. Iadarola gives an overview of the beam induced heat load particularly focusing on the beam screens. In the LHC, it was observed that the heat loads are much more than what was expected from impedance and synchrotron radiation (SR). This difference is not yet understood and a dedicated Task Force was recently put in place, led by L. Tavian. The first observation is the dependence on the different filling schemes of the LHC, where for 100 ns or 50 ns the heat load agrees with the predictions based on impedance and SR only. For shorter bunch spacing, a big component is added, caused most likely by heat-load coming from e-cloud.

No significant evolution is observed during Run II and in particular after mid 2016 and for the worse sectors 1-2, 2-3 and 8-1. Following the question of O. Brüning about the lowest isolated points in the heat load graph, G. Iadarola explains that these correspond to 50 ns fills. The differences among the different sectors seem to have appeared more violently after LS1 and this is a quite fundamental feature to be understood in particular for HL-LHC. Indeed, a collaboration between WP2 and WP9 was undertaken in order to make a heat load inventory with respect to impedance and SR (analytic estimates) and also e-cloud (numerical simulations). These were further cross-checked against LHC studies and machine observations.

Regarding the arcs, the available margin of 7 kW was used to cope with e-cloud. Regarding HL-LHC this margin is reduced to 4 kW. Answering a question of S. Redaelli, G. Iadarola replies that the data is scaled from 6.5 TeV to 7 TeV. O. Brüning stresses that for the ultimate energy exploitation of the LHC, this implies an additional increase of the order of 30 % from SR.

G. Iadarola explains the e-cloud model used for the heat load extrapolation, where an element-by element estimation was built and compared to the LHC observations. Using PyECLOUD simulations, the heat loads are estimated for different elements and SEYs as a function of bunch intensity. The heat load scales in a non-linear way with intensity in particular for the drift. L. Rossi remarks that for very high intensities, less heat load is expected for the quadrupoles.

Using the measured heat-load, SEY estimates can be made for each sector: high heat load sectors correspond to a high SEY of 1.35 and low load sectors to an SEY of 1.25, dominated by the heat load in the quads. An extrapolation to HL-LHC can be thus made. The good news is that the low heat load sectors (i.e. half of the machine) can be scrubbed to an adequate level corresponding to the available cooling capacity of 8 kW/arc. For an SEY of 1.35 though, the expected heat-load of 10 kW/arc is not acceptable for HL-LHC. L. Rossi remarks that even by coating the quadrupoles, the heat load just fits in the available capacity. O. Brüning points out that the difference before and after LS1 has to be understood. L. Rossi asks if this high heat load would allow some scrubbing. G. Iadarola replies that actually this is not observed in the present LHC. It seems that there are two contributions, one that conditions and one that does not.

Regarding the IT area, the e-cloud should be mitigated with a-C coating. When lowering SEY to 1.1, an important e-cloud suppression of one order of magnitude is observed. As coating is not applied in all the area, a total of around 400 W is estimated. S. Claudet stresses that this is in addition to the heat-load from debris and R. Van Welderen adds that this corresponds to 700 W, clarifying that the heat load is taken by the tungsten. Element by element tables are shown, for all IRs. O. Bruning enquires if the stand-alone magnets should be also coated and S. Claudet answers positively. G. Arduini adds that this is one of the conclusions of the study and G. Iadarola points out that any element which does not present a major coating effort, should be indeed coated. Some cross checks are finally pending for stability and multi-turn electron accumulation in the low SEY regime.

A similar study was done for each one of the LSS magnets, and the most critical ones in the experimental IRs are shown, where an order of magnitude reduction is achieved by SEY below

1.1. It is indeed stressed that IR1 and 5 are cooled by one cryo-plant, but IR2 and IR8 will load the neighbouring arc, where cooling capacity is limited. It is thus a good idea to coat the matching section. L. Tavian asks why these quadrupoles do not behave like the ones in the arc cell and G. Iadarola answers that this is due to the different beam sizes and magnet strengths.

Baffle plates are presently installed behind the pumping slots of all stand-alone magnets at 4.5 K. Some will be operating at 1.9 K, but the same strategy should be applied to them as a precaution. The back-up solution may be the 8b4e scheme, which proved the e-cloud suppression during the present run, with a factor of four reduction in heat load. The presentation ends with a summary and conclusions. O. Brüning congratulates G. Iadarola and the WP2 team for all the work done and encourages further studies in order to understand the present heat load discrepancies and impact to the HL-LHC.

Expected Cryo cooling capacity, D. Berkowitz Zamora - slides

D. Berkowitz Zamora first compares the cryogenic configuration between LHC and HL-LHC. The Sector 2-3 and 7-8 will be the weakest, as the cooling capacity is not changed, these sectors have triplets and are cooled by "weak" plants. A schematic of the distribution of the refrigeration power in the existing cryo-plants is given, with an emphasis on the distribution losses to be taken into account.

A similar table of data as the one presented by G. Iadarola is shown, where the main unknown is the heat load from e-cloud. In this respect, the remaining capacity available for e-cloud is quantified. The evolution of beam screen heat load shows that the available capacity will be reduced from 6 to 3 kW in the HL-LHC era. Indeed, the major part of the heat load increases in the beam screens. There are similar levels of heat load for a given circuit across the eight plants, but the capacity transfer from this available margin does not come for free.

A matrix of the different cooling circuits is presented. The capacity of the strong Sector 4-5 is used to cover the RF needs for cooling. D. Delikaris mentions that it is not excluded to have an upgrade of a cryo-plant in P2 and 8. In the question of O. Brüning about the time needed, S. Claudet replies that it should be around three to four years, which may fit with the period after LS3. O. Brüning asks if it will be possible to have an in-situ coating in IR2 and 8. V. Baglin answers that it can be done for a cold bore diameter of 74 mm. G. Arduini stresses that indeed the preferred solution is to act on the source of the problem.

The cooling capacity at the refrigerator is further detailed and compared between LHC and HL-LHC, including the available margins. In the HL-LHC era, all sectors are high load ones (above 10 kW). Sector 5-6 is the strongest with respect to margin, whereas sector 2-3 and 7-8 are the weakest.

Regarding the stand-alone magnets, the short-term solution is to increase the cooling capacity and the long-term solution is surface treatment. V. Baglin mentions that there is a risk analysis initiated for the coating, triggered by F. Bordry. O. Brüning mentions that this was asked for its installation for testing in the machine before LS2, as commented by F. Bordry in a previous TCC. V. Baglin stresses that it would be important to know if the coating works before LS2.

The beam screen heat load averages for the different stand-alone magnets is given, with a total load of around 600 W from e-cloud. Valve opening will likely become the limiting factor before LS2, and it is already the case for some magnets in RunII. The change of valves is thus recommended during LS2. Finally, it is shown that the a-C coating reduces cooling requirement for future cryo-plants. A conclusion is finally presented, stressing that there is a need to better understand in measurements and calculations any hidden sources of heat load.

Discussion

O. Brüning points out that the plans of further upgrade of LHCb will trigger additional heat load in IR8. V. Baglin asks if the Q4 and Q5 in IR1 and 5 which will not be replaced could be coated in situ. P. Fessia replies that they will be moved to the surface and that the beam screen has to be rotated in place. V. Baglin stresses that there may be a risk with the coating and that the project has to address this. O. Brüning understands the argument for coating all the matching sections and the TCC indeed supports this, as a study. It would be important to make the case in Chamonix, in front of the MAC.

Length of the 11 T dipole magnet, S. Izquierdo Bermudez- slides

S. Izquierdo Bermudez reminds the TCC of the requirements and design evolution of the 11 T dipole, including the reduction of radius and the replacement of the magnetic lamination with non-magnetic one at the extremities. Due to time constraints and uncertainty with the final length of the coil, it was decided not to incorporate any further adjustments to the prototype, but measure the differences and take them into account for the series production. The performed magnetic measurements show that both the TF and integral fields are within 10 units of the expected value for the collared coil measurements. There is some difference in the different apertures which is larger for the short model than the prototype. A good agreement of the TF with respect to the model was found in cold measurements but for the short model there are only accurate measurements of the central field but not of the integral. From the cold mass measurements at room temperature and the measurements at cold on the short models, it is observed that there is a need to adjust the field integral. There are two options, namely modifying the length or modifying the trim current profile. The proposed solution is to increase the physical length by 40 mm, as it is easy from the manufacturing point of view. The use of the trim to correct the integral field mismatch would require to operate above nominal current decreasing the margin to quench. If further refinement is needed, the number of magnetic laminations could be further modified. Every 10 mm error corresponds to a 20 A shift in the trim circuit.

Discussion

O. Brüning stresses that this is indeed a very good idea, minimising risks for the magnet production. L. Tavian questions whether there is an impact of the extra length to the design of the by-pass cryostat. S. Izquierdo Bermudez replies that this was anticipated and some space was already left, in order to assure complete transparency of all systems with respect to this modification. M. Martino stresses that from the powering point of view the trim is preferable. P. Fessia mentions that by keeping the integral field, the margin for quench is reduced. O. Brüning takes note of the statement of EPC but he proposes to endorse the proposal. P. Fessia further points out that a document with the changes is being prepared and it has to be further checked for its impact to all the system.

ACTION (WP3): The TCC endorses the proposal for increasing the coil length of the 11 T dipole for adjusting the TF and an ECR must be issued in this respect.

The next TCC meeting will take place on the 23rd of November 2017.