SUMMARY OF SESSION 2 – MAGNETS AND SPLICES CONSOLIDATION SHUTDOWN 2010/2011

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Abstract

Session 2 aims to highlight issues to be faced before 7 TeV operation can be achieved, specifically concerning superconducting magnets, interconnection and internal splices and closely related systems. This was initially intended to be the object of the next shutdown starting December 2010 and extending into 2011.

INTRODUCTION

In this session five presentations were given related to superconducting splices and one related to the quench behaviour of dipoles observed in sector 5-6 during the 2008 hardware commissioning:

- Overview of all superconducting splices in the LHC machine: N. Catalan Lasheras
- Minimum requirement for 13 kA splices: A. Verweij
- Status of splices in 13 kA circuits: P. Fessia
- Status of splices in 6 kA circuits: J.-P. Tock
- Scenarios for consolidation intervention: F. Bertinelli
- Dipoles retraining for 7 TeV: E. Todesco

In summarising the session the order of presentations is not followed.

MINIMUM REQUIREMENT FOR 13 KA SPLICES

Different types of defects were described, used for both modelling (as single sided) and for FRESCA tests.

FRESCA tests have been performed on three samples with purposely built in defects. The thermal runaway time is measured for different currents. These tests allow to estimate the effective heat transfer factor, then used to model the LHC machine. Note - specifically for the design of the new insulation - that LHe cooling gives about 1-2 kA improvement over an adiabatic model.

Conservative assumptions in modelling are made for the copper RRR of cable, busbar, U-piece and wedge, lower values than in previous models.

Updated results for the maximum additional resistance R_{addit} were presented:

- 3.5 TeV:
  - RB: max. R_{addit} = 76 μΩ
  - RQ: max. R_{addit} = 80 μΩ

  The previous (statistical) estimate of the maximum resistance still present in the machine is 90 μΩ. The current state of the machine just allows for 3.5 TeV operation, since it is considered extremely unlikely that all critical conditions (high warm resistance, low cable and busbar RRR, single sided defect, poor cooling) occur simultaneously. Ongoing RRR measurements at 25K should be pursued to provide further information on busbar copper.
- 5 TeV:
  - RB: max. R_{addit} = 43 μΩ
  - RQ: max. R_{addit} = 41 μΩ

Operation at 5 TeV will require to previously localise and repair those splices above these values.

- 7 TeV:
  - RB: max. R_{addit} = 11 μΩ
  - RQ: max. R_{addit} = 15 μΩ

A better knowledge of copper RRR will not change these numbers.

Also to be considered is that the soldered joints may have a resistance degrading in time (fatigue, shocks) and that their measured room temperature resistances may not systematically be representative of their resistance at cold.

In conclusion for 7 TeV operation it is recommended to repair the worse splices and systematically add a shunt to all 13 kA splices. This is dimensioned to a 16 x 2 mm^2 cross-section, to be tested in FRESCA.

STATUS OF SPLICES IN 13 KA CIRCUITS

The complex sequence of activities associated to a splice consolidation was presented, highlighting the main issues to be solved in the ongoing development work.

The worse splices will be repaired (high SC resistance, high R8, misalignments). Samples were made with varying overlap between cables and their SC resistance measured: a 2 nΩ excess resistance - such as measured in the LHC machine with the nQPS – will have only a few mm overlap. Together with electromagnetic forces between cables tending to separate them, this is considered to represent a mechanical risk for the machine. Other possible explanations for this excess resistance are oxide layers or overheated SC cable.

The soldering and QC process were improved in the 2008-09 shutdown, as well as our understanding (positioning of inductor) with potential for further progress (filling voids with copper, shape of inductor).

The shunt requirements were listed, and a potential design presented. It is planned to solder the shunt with lower melting point eutectic Sn-Pb. Different heating technologies will be evaluated. A mechanical clamp will be added.

A new insulation will be required that shall also provide transversal restraint.

SCENARIOS FOR CONSOLIDATION INTERVENTION

It is estimated that ~15-20% of the splices will require repair for 7 TeV operation. This is based on the limited experience with R16 measurements in the 2008-09 shutdown. Unfortunately diagnostics methods do not allow to localise these splices. It will therefore be necessary to systematically open all interconnects (open W bellows, remove thermal screens, cut M sleeves, remove insulation) for local, invasive resistance measurements. In addition to the repair, the shunt and clamp will be systematically added.

In addition to this splice consolidation program, there is a considerable volume of further work associated to magnets, splices and related systems already known (e.g. DN200 pressure relief nozzles, etc.).

The duration of a shutdown is estimated considering past series experience. "Duration" is intended as the time between the first W bellows opening and the last W bellows closed, including testing of the insulation vacuum: times for cryogenic warmup, pressure tests, cooldown, final ELQA and commissioning need to be added.

The resources to be used for the main splices consolidation work alone are estimated ~100 persons, of which ~45 present at CERN, the rest to be integrated.

Different scenarios were considered for the main splices consolidation work. With a throughput of 50 interconnections / week for critical activities (an ambitious value), the first sector would have a duration of 14 weeks, the second would be finished 5 weeks later etc.

Larger throughputs (more resources working in parallel) will considerably increase quality risk, affecting in particular supervision, coordination and Quality Control and are not recommended.

Different scenarios can be discussed by considering the workload distributed over one or more shutdowns. Important issues to be evaluated are the impact to the physics program, radioprotection/ALARA, the amount of additional work, the possibility for diagnostics to localise splices to be repaired for 5 TeV.

A consolidation of all sectors will have a duration of one year. Possibilities have been considered of two and three shorter shutdowns.

A Task Force was setup by the LHC Machine Committee to review all superconducting splices in preparation for 7 TeV operation.

STATUS OF SPLICES IN 6 KA CIRCUITS

Failures in splices occurred at Tevatron (fatigue in the magnet leads) and in a cusp joint at Hera. This experience has forced specific attention on the "praying hands" splices of the 6 kA circuits in the Individually Powered Quadrupoles and Dipoles.

An inventory of circuits was presented with currents for 3.5 TeV up to ultimate operation. Within the same circuit, e.g. Q7L2, at least 5 different splice geometries exist, including praying hands inside the cold mass.

First measurements at cold of the busbar and interconnection splices were performed in one area (DS L2). It is recommended to perform this splice mapping measurement systematically before increasing energy above 3.5 TeV.

It is also recommended to implement a nQPS in 2010 to protect busbar and magnets separately.

The geometry of the praying hands was presented, the assembly process used and its traceability, stress computations, FRESCA fatigue tests. While there seems to be no showstopper, the ongoing work will continue: evaluate other design options, further structural calculations, FRESCA tests with fracture analysis, use of tomography in the tunnel, etc.). In some cases (sector 7-8) it may be required to open and inspect some interconnections that were the first to be assembled and were not fully documented.

OVERVIEW OF ALL SUPERCONDUCTING SPLICES IN THE LHC MACHINE

The full inventory of machine superconducting splices, both inside magnets and interconnecting them, amounts to over 100 000 cases. The magnetic energy stored in the circuits, MIITs and hot spot temperatures were computed.

Results from the 2009-10 powering campaign were presented. While there is no showstopper, some circuits will require further investigation: some Line-N interconnections in sector 7-8. RCO, RQ6, some existing non-conformities, inner triplets. Work will continue to perform a risk analysis considering multiple failures and Maximum Credible Incident scenarios.

Work priorities and resources may need to be defined considering the large workload.

DIPOLES RETRAINING FOR 7 TEV

Sector 5-6 was trained up to 6.6 TeV: several Firm3 dipoles (representing 55% of the dipoles present in this sector) showed a slower training than expected.

Different estimates of training times were presented. The MonteCarlo method based on surface SM18 data gives 50 quenches per octant to reach nominal.

The extrapolation of hardware commissioning data gives 110 ± 35 quenches per octant.

The relation of this performance to production data is being investigated: there is no correlation with storage time (neither of cold masses nor cryodipoles), but other factors are being studied (elastic modulus of coils, collars).

Some additional SM18 cold testing could be performed, but only on the small available samples: they could investigate if quenches occur in the straight part or in the collar heads, and what happens after successive thermal cycles.