STATUS OF SPLICES IN 13 KA CIRCUITS

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Abstract

In this contribution we will review what it has been achieved in terms of quality for the 13KA splices during the reassembly of the sector 3-4 respect to the previous production. Issues and requirements that should guide the choices for future consolidation of these interconnects (including the insulation) will be addressed, providing a first view of the ongoing efforts to translate these technical requirements into a viable technical design.

POSSIBLE ACTIVITY SEQUENCE

This document will try to review the main challenges to be faced and solved to prepare the consolidation of the 13 KA splices of the LHC. These challenges refer to the development of new design and procedures, but also to the re-development of previous employed techniques in order to achieve a higher quality standard and higher output for unit of worked time.

1) Interconnection opening requires the establishment of an efficient assembly chain to deal with the W bellows opening, the thermal screens removal, the re-conditioning and modification of the interconnection screens and the interconnection closures. Dedicated workshop shall be operational on surface in order to carry out the reconditioning operation
2) M lines cutting. The optimization of the cutting tool is required in order to increase the number of M lines cut open each day. In addition a fast feedback loop should be put in place between the cutting team and the TIG welding team in order to provide indication on the welding approach to be used. (manual, orbital ...)
3) Protection. New protection for the bus bar during deburring, for the M line flanges during all the interconnect activities (reducing pollution from low melting metals and therefore consequent cracking of the welds) and beam lines should be designed, produced and implemented
4) Interconnection consolidation and repair. For this chapter please see dedicate section in the article
5) Insulation for this chapter please see dedicated section in this article
6) Non Destructive Testing procedures. A set of complementary NdT methods shall be developed and applied in order to objectively characterise the quality of the consolidated interconnects. The quality control procedure should be aimed to reduce at minimum the necessity of expert judgements that are in any case subjective and time consuming to obtain.

THE SPLICES

Present LHC splices should be completely re-done when at least one of these three criteria in true

a) The resistance of the superconductor to superconductor joint is larger than 0.8-1 ηΩ. In this case the criterion is not derived from cryogenic issues or power dissipation issues, but from mechanical stability consideration. After having assembled several interconnect with a variable length of insulation between the upper and lower cable, the corresponding resistance at 1.8 K it has been measured. FEM computations have been performed simulating splices with the same different effective lengths of current redistribution between the upper and lower cable. Due to the change of the current paths, and the consequent change in induced magnetic field, the map of Lorentz forces is strongly affected. This is shown in Fig.1. It is important to remark that for high resistance (matching short effective splice length) the induced forces try to open the interconnection. These forces become positive at about an effective overlap of 10-15 mm providing resistances in the order of 0.8-1 ηΩ.

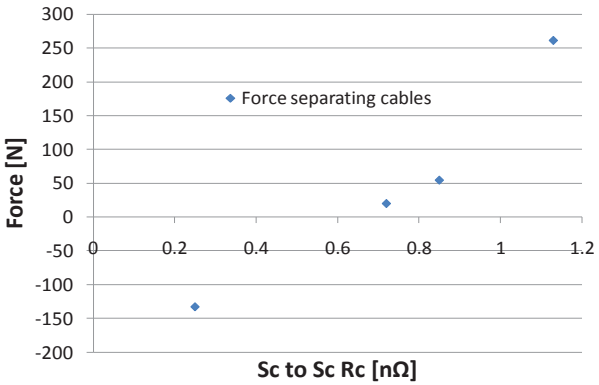

Fig. 1 Forces separation superconducting cable vs. Interconnect resistance

b) The copper to copper in excess resistance is higher than 10-15 μΩ over a length of 8 cm. This witnesses a very poor copper to copper contact with gaps and also possible mechanical instabilities.
c) The misalignment between the different interconnect elements, impair the quality the following consolidation activities.

The interconnects will be re-done using the improved procedures applied during the assembly of the sector 3-4. These procedures will be scrutinised in the incoming

months to put in evidence possible further improvements in quality and execution time.

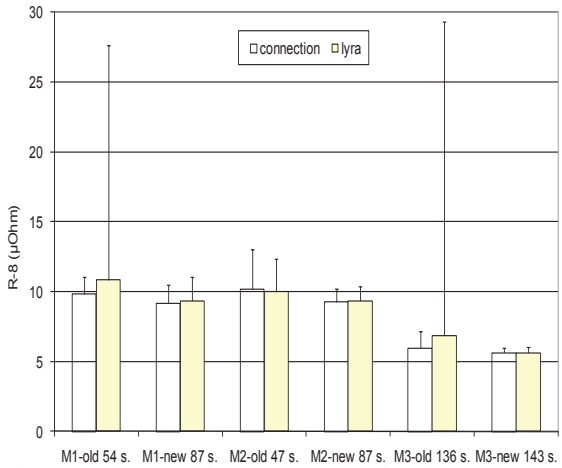

Fig. 2 R8 resistance of the copper to copper junction. Comparison between LHC series production in 3-4 and the statistics after repair

Fig. 2 compares the R8 [1] measurements of the 3-4 interconnect before disassembly (LHC interconnect series production) and the results measured on the new interconnect after 3-4 repair. It is evident that

1) New production present lower median value (in average 1 μΩ less)
2) The large spread strongly affecting the product quality on the lyra side is not present in the new production

The last point has been traced to misplacement of the inductor during the assembly, misplacement that by the way has also strongly affected the heat distribution inside the bus bar contiguous to the splice with under heating of the connection on the lyra side. Careful analysis of the γ-ray pictures of the bus bar, in the magnets dismantled from sector 3-4, demonstrates a larger lack of filling material on the magnet connection side witnessing an important over-heating and matching the previous observations.

CONSOLIDATION OF EXISTING SPLICES

The consolidation of existing splices will probably take place by adding a shunt in parallel to the connection [2].

The aim is to apply a copper section (2 X 15 mm) connected in parallel to the copper to copper junction complying with the following requirements:

1) Do not melt or interfere with the existing junction
2) Apply it without cutting the spools on the top of the quadrupole bus bar
3) Accommodate the shape defect of an existing interconnection
4) Being redundant by design
5) To be easily inspected and declared acceptable by QC
6) Be of rapid installation and minimize the risk of error by design
7) Use “small” tooling allowing co-activity
8) Use of tooling easy to multiply
9) Possibly industrially based tooling

Present possible designs are shown in Fig..3 Fig. 4 and Fig. 5

Fig. 3 Shunt implementation design featuring a rigid shunt and mechanical restrains

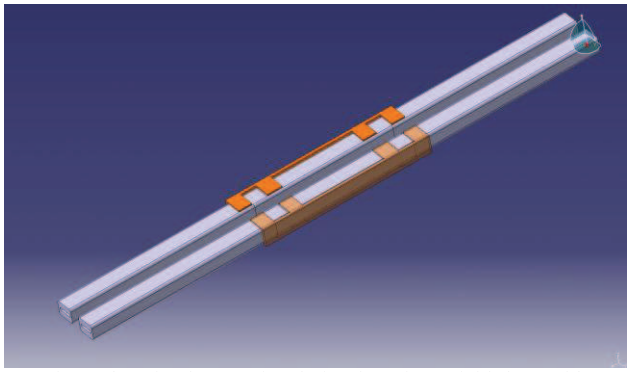

Fig. 4 Shunt implementation design featuring a rigid shunt with redundant connection points

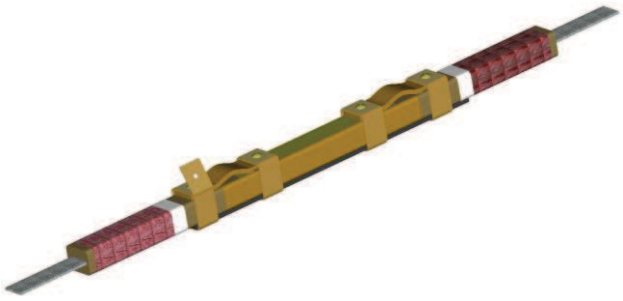

Fig. 5Shunt implementation design featuring braid type shunt with mechanical restrains

The shunt will be applied with soldering. For the moment the chosen alloy is Sn-Pb eutectic in order to have a melting point lower then the one of the Sn-Ag used in the interconnect. In order to optimise the shunt application, in term of quality results and execution time, different technologies are being tested, i.e. equipments derived from machine implied spot welding methodology to system based on resistive heating and induction.

NEW INSULATION

Due to the presence of the shunt the electrical insulation system shall be changed. The new electrical insulation should fulfil the following requirements:

1) Provide electrical insulation. Bus bars are protected with polyimide 15 mm wide, 50% overlapped and they are separated by 12 mm of He. Total distance for electrical path 27 mm. This is equivalent to 4 KV at 1 bar.
2) Accommodate the new shunt
3) Accommodate the differences in bus bar geometry due to shape defects
4) Provide enhanced cooling
5) Block lateral movement during the ramp up in current

It is important to underline the necessity of a lateral mechanical restrain. In function of the support mode (that depends on the quality of the bus bar assembly inside the cold masses) the repulsive electromagnetic forces can induce tensile stresses in the range from 9 MPa till 50 MPa. These stress values are induced by the bus bar bending in the most external fibre and are cycled with the machine cycle. If unconstrained, these loads constitute therefore a fatigue loading term that should be taken into consideration during the design phase. Fig. 6 illustrates a possible design of insulation conceived also to block lateral deformations.

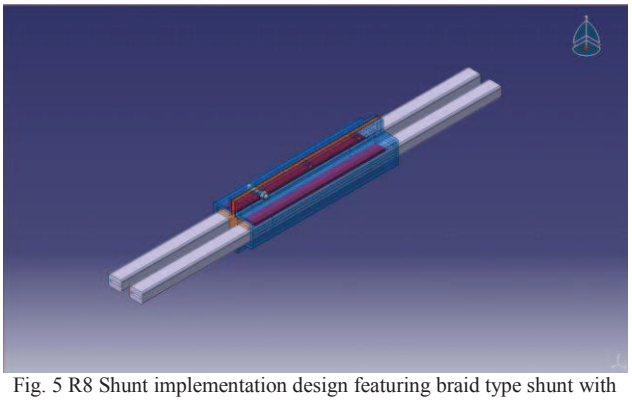

Fig. 5 R8 Shunt implementation design featuring braid type shunt with mechanical restrains

The present solution foresees to have thermoplastic components formed by injection moulding.

CONCLUSIONS

A 1st analysis of the activity sequence necessary to consolidate the 13 KA splices of the LHC has been proposed. It is evident that many steps from cutting to welding need in depth analysis and rethinking in order to be able to provide the required output without compromising quality. Concerning the main activities related to the electrical junction stabilisation, it has been demonstrated that the mastering of the interconnection operation is largely improved respect to the series production. This improvement is linked to procedure optimization and improvement in technical sequences. It is important to remark that these improvements have been possible thanks to the direct involvement of CERN technical staff on the ground in performing the work and or in directly supervising it. This shows also the importance to stick to a model with strong CERN involvement for the final machine consolidation.

The proposed designs for the shunt need to be optimised and compared among them taking in to account the difficulties in installation induced by the surrounding tunnel environment. The objective is to integrate this shunt as pure electrical safely device avoiding to require that it also stands mechanical forces. This will be done in order to avoid possible deterioration of the performance during the machine exploitation. Mechanical elements will be added in order to keep the different interconnection components together also in case of incident delaying the possible creation of an electrical arch.

The new insulation will be design to provide enhanced cooling with direct helium contact and to limit the bus bar deformation during the powering cycles.

The solutions proposed in this article should be intended as 1st draft. The team in charge of this activity has started to work together only from end of November and future analysis could bring to substantially different choices.

REFERENCES

[1] Francesco Bertinelli, Scenarios for Consolidations Intervention, Chamonix 2010 Workshop, Session 2.

[2] A. Verweij, Minimum Requirement for 13 kA Splices, Chamonix 2010 Workshop, Session 2.

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