SPLICE CONSOLIDATION: WHAT WE WILL DO: STATUS OF MAIN TECHNICAL SOLUTIONS.

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Abstract

The present paper will provide an overview of the main technical developments that have been carried out during the year 2010 in order to prepare methodologies, procedures and tooling to consolidate the 13 kA LHC splices and to make them capable to run, without any risk, at the LHC ultimate current.

Many successive interventions and operation are necessary to allow intervening on the above mentioned interconnections [1,2,3,4], but in this work we will describe only few of them trying to put in evidence the goals and the advantages respect to previous adopted solutions.

REDOING THE 13KA INTERCONNECTIONS

A not negligible fraction of interconnections will require complete rebuilding, meaning de-soldering, reshaping of the superconducting Rutherford cable, re-soldering of the joints with new interconnection copper pieces. Present estimation indicates that about 15%-20% of the LHC 10200 13 kA magnet to magnet splices should require this type of intervention [5]. The reasons that can lead to decide to completely rebuild an interconnect are

1) High resistance superconductor to superconductor. It would be known beforehand thanks to machine survey via the nQPS system (about 10 units).
2) High resistance of the copper to copper junction on the interconnect extremities, showing the lack of good connection between the bus bar stabiliser and the interconnection copper piece. These interconnects will be identified thanks to local warm electrical measurements performed after having opened the sleeves protecting each line.
3) Very bad alignment between interconnection components that could impair the results of the following consolidation activities
4) Large/extreme defect detected during the visual inspection

The new developments have the goal to

1) Improve the temperature distribution during the soldering process in order to guarantee a proper copper to copper junction, minimising the region of solder affected in the bus bar
2) Make possible the execution of the connection working through the spool corrector buses that are running on the top of the qudrupole lines. The aim is not to open the connection of these buses, activities that would engender many correlated control work and require the bridging of the interconnect, substituting each connection with two new connections
3) Possibly reduce and optimise the intervention time

In order to reach the described objectives the following technical development have been carried out

1) The modification of the heating profile (thanks to newly developed inductors) in order to shorten it down and reduce the heating of the nearby bus bar by conduction
2) The mechanical modification of the soldering clamping system to allow intervening through the spools cable
3) The introduction of a cooling system to reduce the cooling time after completion of the soldering

As results of these modifications the region inside the bus bar, where the solder alloy was partially melted, has been reduced halved and the machine interconnection time was reduced from 15 mn to 8 mn.

SHUNT DESIGN

Present baseline features for the

1) RB lines two fully redundant shunts on each side of the interconnect. Fig. 1
2) RQ lines one shunt on each side of the interconnect. Fig. 2.

The design team is pursuing the efforts in order to find a way to apply a second redundant shunt also on the quadrupole bus bar, where the presence of the spools and the important deformation of the interconnection pieces, which occurred during the installation phase, make this operation more complex and risky for the integrity of the spools circuit.

The present dipole shunts (Fig. 3) design features

1) The capability to carry 13kA withstanding large soldering defects (4 mm X 15mm), low RRR value of the bus bar copper (100) and of the shunt (150) and maximum temperature reached of 300K (Fig. 4).
2) Incorporated SnPb solder alloy reservoirs to eliminate operator intervention, to make the process more reproducible.
3) Soldering by capillarity to originate a solder wave capable to reduce gas enclosure and therefore improve the solder joint quality. This is helped by the presence of degassing holes and grooves and grooves to enhance the capillarity.

Unfortunately it has been shown that despite all the efforts it has been impossible to guarantees an acceptable rate of successful soldering on rough interconnection surfaces because of

- The possible presence of large shape defects
- The important surface oxidation and contamination

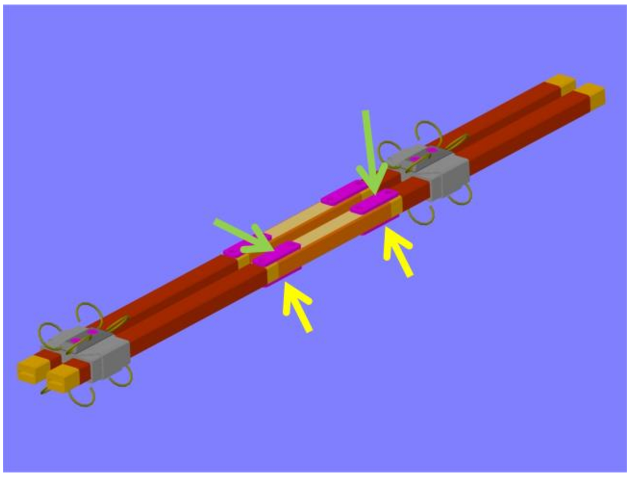

Figure 1. The shunts applied on the dipole bus bar

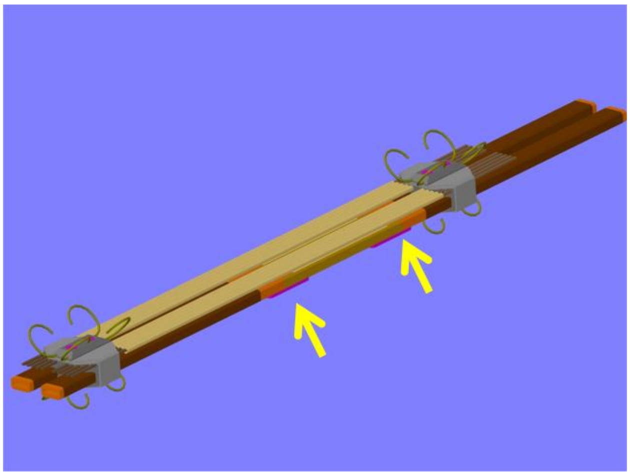

Figure 2. The shunts applied on the quadrupole bus bar

Figure 3. Shunt prototype integrating solder alloy reservoir, capillarity grooves and degassing holes

In order o achieve a systematically good quality it has been necessary to recover a flat, planar and clean surface on the two sides to the copper to copper connection. This has been possible thanks to the use an ad hoc milling tool that allow eliminating up to 1 mm of copper thickness.

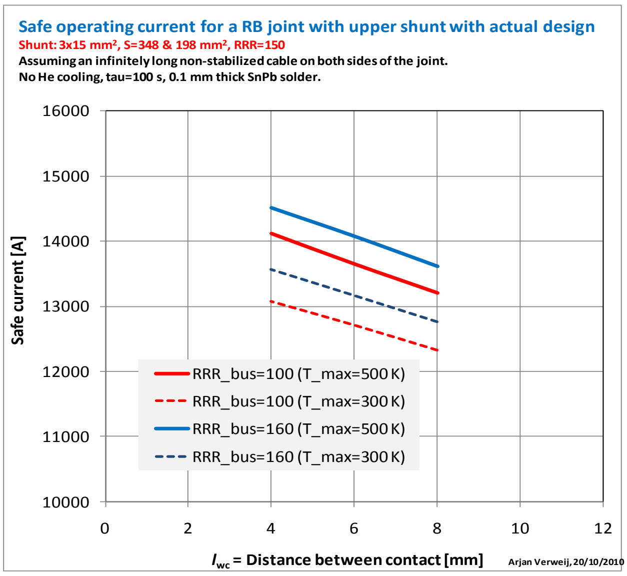

Figure 4. Safe current that can be carried by the interconnection equipped with one shunt in function of the distance between the nearest soldered points

THE INSULATION BOX

The new insulation system shall fulfil many requirements:

1) Provide the insulation strength better or equal to present insulation
2) Restrain the lateral deformation (due to Lorentz forces) of the interconnect in order to significantly reduce associated stresses
3) Being of easy assembly, not constraining the bus bar in unnatural positions, positions that could generate new unforeseen stresses, complying with bus bar shape defects up ±3 mm in horizontal and ±5 mm in vertical
4) Fulfil cryogenic conduction and hydraulic impedance requirements
5) Withstand radiation dose of the worst arc interconnect for 20 years (1 MGy including a safety factor 10)
6) Improve electrical separation between spools and main circuits
7) Providing cooling. In this respect the available estimation indicates that on a non shunted connection the presence of effective cooling could add up to 4kA to the safe current respect to adiabatic case [6]

The developed design (Fig. 5) fulfils all the previous requirements with the exception of the dielectric strength that is larger than the LHC design requirement (3.1kV in helium gas 1 bar), but lower with respect to the present LHC insulation. New feature will be added to increase this margin.

From the mechanical point of view the new box allow reducing the induced stresses from 40 MPa and 58MPa, on the two interconnection extremity regions, to respectively 17 MPa and 5 MPa.

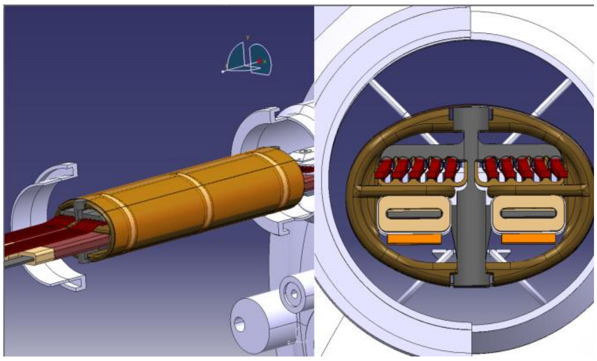

Figure 5. Insulation and restraining box for quadrupole line

INTERCONENCTION REINFORCEMENT

Two type of mechanical reinforcements for the interconnection are foreseen. Their goal is to keep the interconnection pieces in mutual contact in case of hypothetical mechanical failure. The first piece will block together the U and wedge piece of the interconnect. The second component will block the shunt in position. Both systems are in the conceptual design phase.

THE SM18 TEST

To validate the design a test has been conceived and set up using the test benches installed in the SM18 facility. Spare Q8 and Q9 cryostated magnets have been used in this experience. This has allowed rebuilding a real LHC interconnect with the real cryogenic environment. The use of MQM type magnets has allowed not having active magnets on the fed circuits providing much more flexibility for the test (no inductance) and no risk to damage the coils. The interconnect has been heavily instrumented and equipped with large defects (equivalent to 40-50μΩ). In addition the shunts have been soldered simulating large solder defects (up to 8 mm). The interconnect has been quenched using heaters installed directly on it. Results show that in this condition the interconnect is extremely stable and that no thermal runaway occurs (Fig. 6). This even with very large current up to 14kA kept constant. In this condition the bus bar seems to be more unstable then the interconnect. (Fig. 7).

THE INTERNATIONAL REVIEW

Between the 18th and the 22nd October 2010 an international independent review has scrutinised the advancement of the design work.

The main indications provided have been:

1) The work carried out has been the results of a thoughtful and in depth analysis of the interconnection behaviour and needs
2) The design is well progressing and targeting one by one all open points

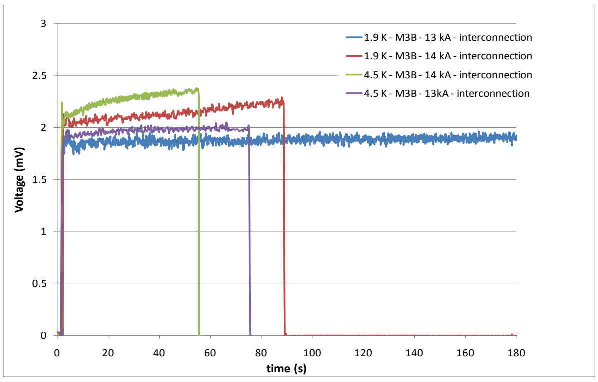

Figure 6. Voltage developed in the interconnects while quenched. Constant values show the creation of a normal zone but without thermal runaway

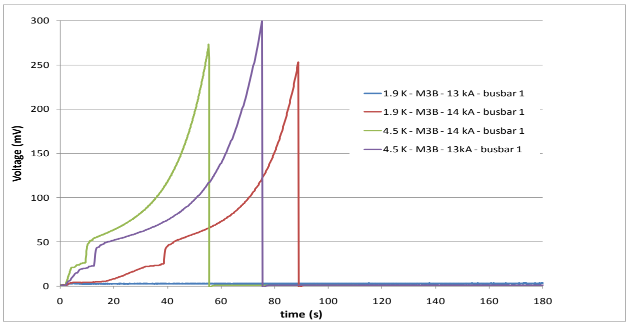

Figure 7. Voltage developed in the bus bar while quenching the interconnect. Rising values show the creation of a normal zone, with start of thermal runaway

3) The LHC present interconnect is not a reliable connection also when re-built.
4) The application of redundant shunt should be pursued also for the quadrupole line as well as the clamp application
5) The understanding of the data of SM18 should be pursued looking at the implication for a fully adiabatic case

CERN takes in the highest consideration these recommendations and will do the maximum effort to fulfil them, balancing their application with the added operational risks that could be originated (for example) by the application of quadruple redundant shunt. This action could put at risk the spool integrity due to proximity.

NEXT MILESTONES

The development phase should be completed in the beginning of summer 2011. This phase will be followed by the component and tooling procurement. Delivery of material should start in fall 2011 to be completed in the early spring 2012. The target for November 2011 is to have at CERN all components and tooling necessary to carry out the whole intervention on a LHC sector.

CONCLUSIONS

The development of technical solutions for the LHC consolidation is ongoing. It is targeting the development and test of components, but also the improvement of tooling and procedures. The correlation between quality, time and costs has been taken into account since the design phase. Present solutions are sounds and have been deeply scrutinised at CERN and by an international review.

REFERENCES

[1] "Work organization for splice consolidation", F. Bertinelli Chamonix 2011 LHC Performance Workshop

[2] "Cryomagnets, Interconnections, Superconducting Circuits: What to do in 2012/13 if you are not consolidating splices?", J.P. Tock Chamonix 2011 LHC Performance Workshop

[3] "Probability of burn-through of defective 13 kA joints at increased energy levels", A. Verweij Chamonix 2011 LHC Performance Workshop

[4] "Status of splices in 13 kA circuits" P. Fessia Chamonix 2010 workshop on LHC performance.

[5] "Scenarios for consolidations intervention" F. Bertinelli, LHC Performance Workshop - Chamonix 2010

[6] "Sensitivity study of the safe current" Arjan Verweij, Task Force LHC splices consolidation, 10 Dec 2009