SCENARIOS FOR CONSOLIDATIONS INTERVENTION

F. Bertinelli, CERN, Geneva, Switzerland

Abstract

A Task Force has been set up to review the status of all superconducting splices in the LHC machine and prepare the necessary consolidation actions for 7 TeV operation: the mandate, organisation and working time frame are reported.

The first consolidation actions could start during the shutdown 2010-2011. Preliminary considerations are presented considering workload, resources and durations.

LHC SPLICES TASK FORCE

The LHC Machine Committee received and endorsed a proposal for the creation of a dedicated Task Force [1]. The mandate is to review the status of all superconducting splices in the LHC machine and prepare the necessary consolidation actions for 7 TeV operation.

It is considered important to analyse splices over complete circuits (from DFB current lead to current lead), i.e. from the point of view of powering as opposed to the traditional point of view of individual equipment holders.

The electrical and structural specifications are to be defined for both 5 TeV and 7 TeV operation.

The timeframe is to develop and validate design improvements, implementation procedures and quality control in time for the shutdown starting December 2010. In order to leave sufficient time for the shutdown to be adequately organised (procurement of components and tooling, organisation of procedures and teams, training etc.), the Task Force should therefore aim to complete its work by June-July 2010.

Also important is to evaluate the interaction with other systems that could either affect or benefit from the same consolidation action.

The members of the Task Force represent different departments and groups, bringing different skills and experience.

The Task Force reports to the TE Technical Meetings and to the LMC for approval.

Since November 2009 the Task Force has met weekly. The top work priorities reflect the issues of the LHC machine, all reported separately: analysis [2] and design consolidation [3] of the main interconnection splices, 6 kA praying hands splices [4], and "all the other" cases [5], in particular 600A splices and triplets.

Minutes and presentations are openly available on the site: www.cern.ch/LHCsplices.

To note that several members are currently still heavily involved with commissioning work and can contribute only a small portion of their time to the Task Force work.

Also to note that if an external review of the consolidated design will be required by Management, this will exceed the above timeframe unless it is launched in parallel within the coming months.

SHUTDOWN STRATEGY

While the consolidated design for the main 13 kA interconnection (IC) splices is still in early development, it is possible to make some first considerations.

An important issue is whether all these splices will need consolidation. One approach considers experience from the 2008-2009, namely the local "R16" warm resistance measurements. Table 1 summarises the quantities, type and location of the 236 measurements done, i.e. a sample of ~2% of the overall IC splices. The chosen locations for R16 measurements were driven by previous "segment" warm resistance measurements, thereby introducing a bias in this sample.

	OLD splices																	
	R16 measured						repaired for R16						repaired for visual					
	M1		M2		M3		M1		M2		M3		M1		M2		M3	
	bias	no bias	bias	no bias	bias	no bias	bias	no bias	bias	no bias	bias	no bias	bias	no bias	bias	no bias	bias	no bias
S12	0	0	0	0	13	11	0	0	0	0	9	2	0	0	0	0	0	1
S34	0	12	0	12	2	14	0	3	0	0	1	2	0	2	0	0	0	2
S45	0	2	0	2	8	12	0	0	0	1	6	3	0	0	0	0	0	5
S56	0	6	0	2	0	32	0	0	0	0	0	1	0	1	0	0	0	10
S67	16	18	14	17	24	19	2	5	4	2	14	3	3	4	4	2	6	3
Total	16	38	14	33	47	88	2	8	4	3	30	11	3	7	4	2	6	21
	54		47		135													
	236						58						43					

Table 1: summary of R16 measurements data

However for each "biased" splice measured, there is its neighbouring parallel splice that can be considered unbiased. On the basis of this unbiased population - unfortunately a small sample, e.g. ~1% for the dipole M3 splices, see Fig. 1 – it is estimated that ~15% of the 10 000 splices in the machine will present an excess R16 resistance of at least 10 μΩ, the typical limit for 7 TeV operation, and will therefore require consolidation.

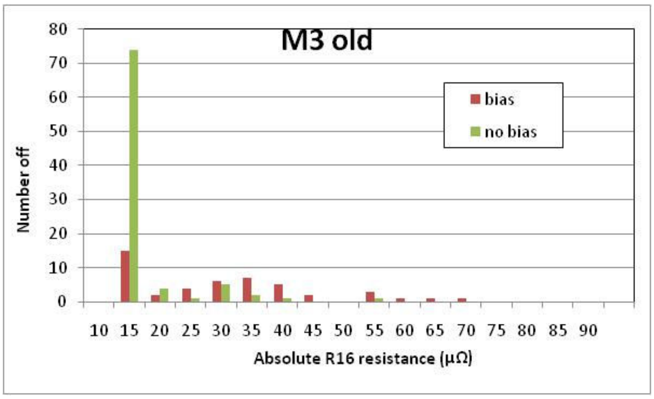

Figure 1: R16 data for dipole M3 splices

Unfortunately the currently available diagnostics for identifying these splices - the segment measurements at warm - can at best localise segments that contain typically 2 or 3 splices for dipoles, 8 for quadrupoles, but not localise specific individual splices. The only existing solution is then to cut open the sleeves for all the splices concerned to allow a local resistance measurement.

In addition it was noted that in the 2008-09 experience a consistent number of splices presented acceptably low R16 resistance values, but were repaired for visual considerations (gaps, misalignments, oxidation). Also that segment measurements for quadrupole lines are limited in their precision due to the higher number of IC splices and the larger dispersion of busbar resistances.

The conclusion is that it will be required to open all interconnects, including cutting all M sleeves, in order to access the splices for invasive, local resistance measurements. It is foreseen that ~15-20% of the splices will require redoing, i.e. desoldering and resoldering according to the improved procedures of 2008-09. In addition it is foreseen to systematically add a parallel shunt and clamp to increase the long-term safety margin [2, 3]. A critical unknown at this stage is how to perform this work without cutting or damaging the adjacent spool splices.

The strategy for a consolidation shutdown is therefore based on this scenario.

A second approach based on the analysis of warm segment data from 5 sectors yields the same conclusion.

ADDITIONAL MAGNETS IC WORK

The known workload for future shutdowns, both for magnets, splices and interacting systems, is already considerable. Group and equipment owners will need to decide on the priorities for intervention. In some cases the intervention will be mandatory, in others it may be done preventively in parallel to the splice consolidation campaign. The following is a preliminary list of known cases:

- Pressure relief nozzles DN200: still to be fitted in sectors 7-8, 8-1, 2-3 and partly 4-5 (60/168 DN200 already done in 2008-09). Without coactivity difficulties, a team can typically perform this work in 5-6 weeks. Teams are typically dedicated, with the exception of opening and closing of W bellows: this work could be done in parallel to splice consolidation.
- "single event splices" for 5 TeV operation: from warm segment measurements the number of splices in the machine that present an excess R16 resistance of at least 40 $\mu\Omega$, the typical limit for 5 TeV operation, is estimated to ~20-100 splices. If these could be localised at cold (thermal amplifier method [6]) one could envisage their repair using the 2008-09 procedures and local warm-up [7]. Similarly a few cases will arise from cold pyramid measurements showing segments with 2 nΩ excess resistances that could require a local intervention (e.g. MB circuit A31L4 to C31L4).
- Connection cryostats: to be opened for inspection of the busbars to check against transversal deformation, sectors 7-8. 8-1, 2-3 and 4-5. Repairs were stopped assuming operation at 5 TeV for 1 year: these may need be reconsidered (e.g. 3.5 TeV but for longer).
- Repair of vacuum leaks: may be required, e.g. sector 3-4 in sub-sector Q27L4 to Q31L4.
- N-line connections: may be required to be opened for inspection in some cases in sector 7-8.
- 6 kA praying hands splices: may be required to be opened for inspection, e.g. sector 7-8.
- Spool connections to investigate and possibly repair.
- Replacement of magnets: potentially ~4 cases from different reasons (damaged quench heaters, IFS box, nested bellows, SC cable, ...)
- Y-lines: defective soldering as identified by cryogenic operations, e.g. in 7-8, 8-1.
- Stand Alone Magnets Helium Guards: complete the 2008-09 interventions in sectors 7-8 and 2-3.
- DFBA flexible: complete the 2008-09 interventions.
- Damaged radiation and thermal screens: it is known from 2008-09 that several will need to be repaired after dismounting.
- PIMs: RF ball testing will be performed after warm-up, potentially with some replacement work, either preventive or for repair. Use of the tomograph may be required. The option of a full intervention campaign is still pending.
- Non-conformities: today 35 cases known, with additional cases "closed with warnings" and those resulting from Hardware Commissioning to also be cosnidered.

The above list is not exhaustive. In conclusion, any shutdown scenario includes a considerable workload and resources and coactivities must be organised accordingly. Some of this work may be performed in case of shorter shutdowns.

SCENARIOS FOR SHUTDOWNS

The workload compares to that of the series installation work in the years 2005-07: in some ways easier (magnets, with possibly a few exceptions, are already in place, some activities will not be required e.g. jumpers, N-line), but in other ways harder (a repair is never as simple or as good as new, e.g. the potential for root porosities in repaired welds with shorter lips).

For the series work, resources were ~100 workers from the Main Contractor IEG and ~100 CERN workers (including FSU and collaborations) for coordination, QC (including ELQA and VAC), troubleshooting, special activities.

For the 2008-09 shutdown resources were ~100 CERN workers.

Work progress in series installation can be seen from historical data, e.g. from sector 1-2, the last sector to be installed, see Fig. 2 and 3.

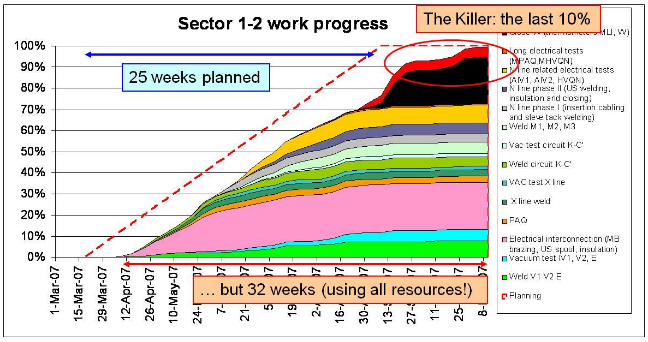

Figure 2: series installation, sector 1-2

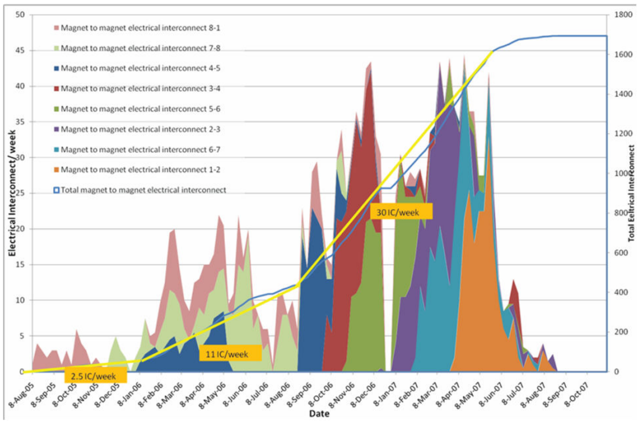

Figure 3: series busbar soldering installation

This experience highlights a few relevant issues:

- Resources were organised to perform critical activities, e.g. busbar soldering, at a throughput of 40 IC / week: the obtained throughput during long periods was actually on average 30 IC / week.
- Once the bulk ~90%, of the work was done, the remainder (consisting of difficult cases, repairs, non-conformities, "natural holes" left for testing) also took a considerable time, difficult to plan and often occupying the most qualified resources.

A first estimate of the duration of splice consolidation for one sector is based on the sequence of required activities and on a throughput of 30 IC / week for critical activities. "Duration" is intended as time from first W bellows opening to last W bellows closing, including final testing of vacuum sub-sectors and a provision for final repairs. In addition one has to consider cryogenic warm-up, pressure test and cool-down times, final ELQA testing and Hardware Commissioning. Other activities would have to be performed in parallel. The first estimate is therefore of 19 weeks for the first sector, with the second sector following 9 weeks later, etc.

The resources required are estimated at ~100 CERN workers (including FSU and collaborations), of which ~45 are present on the CERN site with skills and relevant experience, the remainder ~55 would need to be integrated: the 2008-09 experience shows this ratio to still be manageable with reasonably low risk. As activities progress, this large team would be present in 2, possibly 3, adjacent sectors, already a difficult task for supervision, QC and coordination.

Further increasing the number of inexperienced workers and the number of activities performed in parallel increases the risks and difficulties associated in particular with supervision, QC and coordination. Based on the 2008-09 experience a team of ~100 workers represents a good compromise between resources and risk.

Also to be noted is the impact of the shutdown on the ongoing surface activities of the "core" team.

A second estimate of the duration of splice consolidation is based on a throughput of 50 IC / week for critical activities, see Fig. 4 for the first two sectors. The duration for the first sector is 14 weeks, with the second sector following 5 weeks later, etc.

This increase in throughput is at this stage considered a realistic, yet ambitious, target for the optimisation of tooling and procedures.

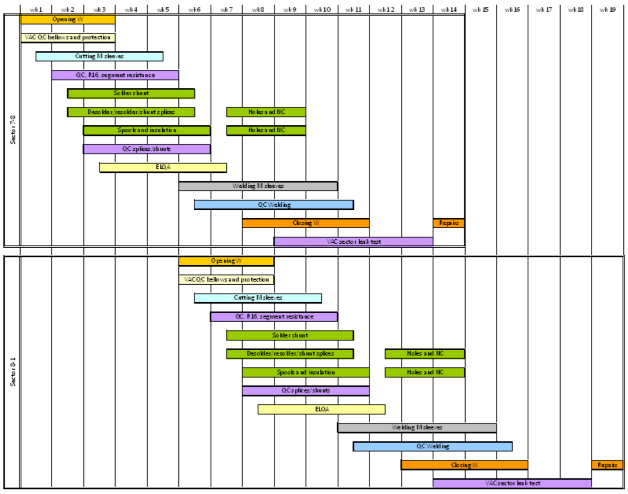

Figure 4: splices consolidation scenario, first 2 sectors, 50 IC / week

Using this scenario, durations of shutdowns depending on the number of sectors to be consolidated can be estimated: all the additional work is assumed to be performed in parallel to the splice consolidation.

Scenario 1: all sectors. The first sector would be finished after 14 weeks, the last 8th sector would be finished after 49 weeks: this implies over a year stop.

Alternative scenarios imply spreading the workload over different shutdowns. They may become attractive if diagnostics allow the identification of those "single event" splices that could then be repaired to allow 5 TeV operation after the first shutdown.

Scenario 2: 4 sectors. The last 4th sector would be finished after 29 weeks. There would then be a second shutdown presumably a year later.

Scenario 3: 2 sectors. The last 2nd sector would then be finished after 19 weeks, followed presumably by 2 more shutdowns of 3 sectors each. One advantage of this scenario would be to allow the early testing at full powering of the adopted solution and the optimisation of working procedures for future shutdowns.

Other combinations clearly can be discussed. They should be compared accounting in particular for:

- the needs of the physics program,
- radioprotection / ALARA considerations: earlier shutdowns are preferred,
- volume of additional work needed,
- the number of resources (and parallelism) introduced. The learning curve associated with introducing and training a large number of resources only pays off for long durations.
- The possibility of unexpected events creating the conditions and necessity for an intervention in a sector.

CONCLUSIONS

A Task Force has been set up to review all superconductor splices and prepare the necessary consolidation actions for 7 TeV operation. Initially these actions were expected to start with the 2010-11 shutdown.

The first priority is the analysis and design of the consolidated 13 kA main interconnection splices. It will be required to access all splices for local, invasive resistance measurements: an estimated 15-20% will be redone, while all will be fitted with an additional shunt and clamp.

In addition to this splice consolidation work, a considerable volume of work is already known for further magnet and related systems activities. Group and equipment owners will need to decide on the priorities for intervention, whether mandatory or of preventive nature.

Resources are planned at ~100 CERN workers (including FSU and collaborations), of which ~45 are present on the CERN site with skills and relevant experience, the remainder ~55 would need to be integrated. This ratio is considered acceptable to allow adequate supervision, Quality Control and coordination. The risk to quality of excessive throughput and parallelism must be avoided.

Estimates of durations have been made based on the experience of series work and 2008-09 shutdown. A consolidation work covering all sectors would take 1 year for the interconnection work alone.

Alternative scenarios can be envisaged where the consolidation work is spread over more years: these could become attractive if diagnostics were developed to localise those few splices requiring intervention to increase energy to 5 TeV operation which could then be repaired with local warm-ups.

REFERENCES

[1] Summary of the 35th LMC Meeting held on 4, November 2009.

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

[3] P. Fessia, Status of Splices in 13 kA Circuits, Chamonix 2010 Workshop, Session 2.

[4] J. -P. Tock, Status of Splices in 6 kA Circuits, Chamonix 2010 Workshop, Session 2.

[5] N. Catalan Lasheras, Overview of all Superconducting Splices in the LHC Machine, Chamonix 2010 Workshop, Session 2.

[6] M. Koratzinos. Do the Splices Limit us to Reach 5 TeV. Plans for 2010 Run, Chamonix 2010 Workshop, Session 1.

[7] P. Cruikshank, What Repair Activity Can Be Done Today on a Locally Warmed Up Sub-sector?, Chamonix 2010 Workshop, Session 3.