WORK ORGANISATION FOR SPLICE CONSOLIDATION

F. Bertinelli, CERN, Geneva, Switzerland

Abstract

The Splices Task Force has worked in 2010 to prepare the necessary interventions for 7 TeV operation. The design solution for consolidating the main interconnection splices is well advanced. The required activities to implement it are described, highlighting working assumptions, missing resources and schedule considerations.

Progress has also been made in assessing other splices, 6 kA praying hands and corrector circuits: results and ongoing work are presented, highlighting priorities for the remaining work.

LHC SPLICES TASK FORCE

The LHC Splices Task Force is composed of twelve members from the EN, PH and TE Departments bringing together different skills and experience. 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.

The first work priority in 2010 was to develop the design consolidation of the main interconnection splices [1]. The second priority was the 6 kA praying hands splices, and thirdly the assessment of other splices, in particular for 600 A circuits and triplets.

Minutes of meetings, presentations and supporting material are available in www.cern.ch/LHCsplices.

The work progress was reviewed by an international committee at the First Splice Review at CERN on 18-22 October, 2010: presentations are available in
http://indico.cern.ch/conferenceDisplay.py?confId=109100
and recommendations are available in
https://espace.cern.ch/lhcsplices/First%20Splice%20Review/default.aspx.

Each recommendation resulted in an action item for specific work and studies to be carried out and followed up under the CERN group structure responsibility, mainly within TE-MSC and TE-MPE, see
https://espace.cern.ch/lhcsplices/Meeting%2036/default.aspx
for example:

- develop comprehensive integrated electrical diagrams → action TE/MPE: N. Catalan Lasheras
- develop comprehensive circuits models → action TE/MPE: R. Schmidt
- double shunt be applied to the quad bus → action TE/MSC: P. Fessia.

The Second Splice Review was planned for September 2011, mainly to discuss production readiness. With the shutdown moved to 2013, this review will be re-scheduled.

SPLICE CONSOLIDATION

The strategy for consolidation was described in [2]. 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.

The "interconnection work" is defined as starting with the first opening of the large W bellows and ending with the closing of the last one. It consists of a sequence of work activities involving several teams and technologies, see Fig. 1. In order to estimate the work duration, some important assumptions are made:

- work sequentially through adjacent sectors as a continuous "IC train" of activities;
- no constraints from radio-protection issues, access (cryogenics, electrical testing, ...), coactivity (transport, ...) ;
- 2 work shifts (6h to 15h and 12h to 21h) for different activities, Monday to Friday, 40 h working weeks for all teams;
- all non-standard magnet and interconnection activities are finished before the arrival of the "IC train", specifically the completion of the DN200 pressure relief nozzle installation and work by the Special Intervention Team (SIT), see [3]. The current preference allowing the longest time at point 3 for DS collimator activities, is to start the IC train work at Point 4 progressing clockwise to adjacent sectors.

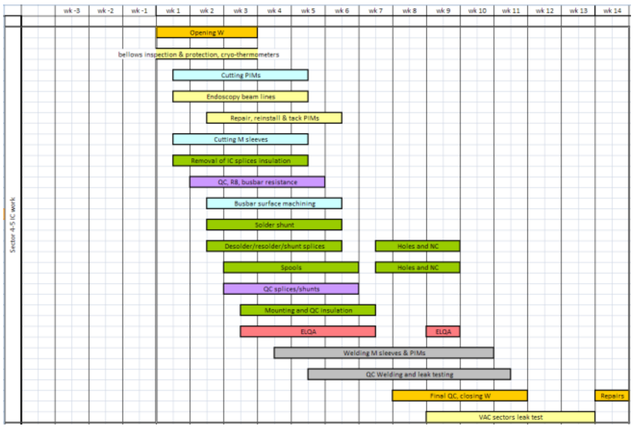

Figure 1: Sequence of work activities for IC Train

These conditions allow the optimal use of working time by the IC train, specifically minimising loss of time for moving teams and equipment around the tunnel.

The work rate for the IC Train is taken to be 50 IC activities / week. Without further contingency included (learning, holiday periods, ...) this implies a duration of "interconnection work" for the train alone of minimum 12 months (14 weeks for the first sector and 5 additional weeks to complete each following sector).

The necessary resources required for the IC train, DN200 and SIT teams are estimated at ~200 persons in the tunnel. A break-down per activity is shown in Fig. 2, showing Quality Control activities representing ~40% of the total.

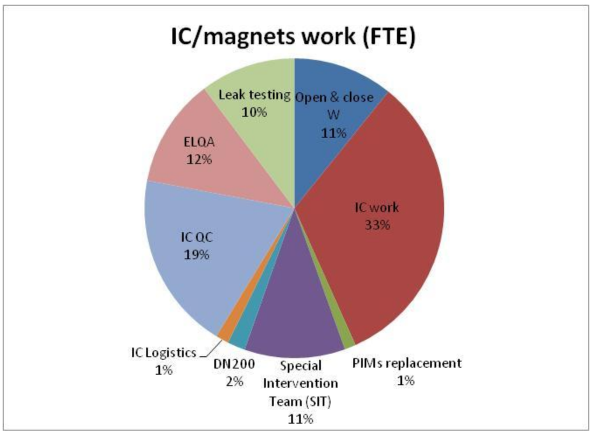

Figure 2: break-down of magnet/interconnections activities

Of the necessary resources, ~1/3 are identified and experienced, although not all present on the CERN site (e.g. Project Associates from Krakow and Dubna) nor staff, see Fig. 3.

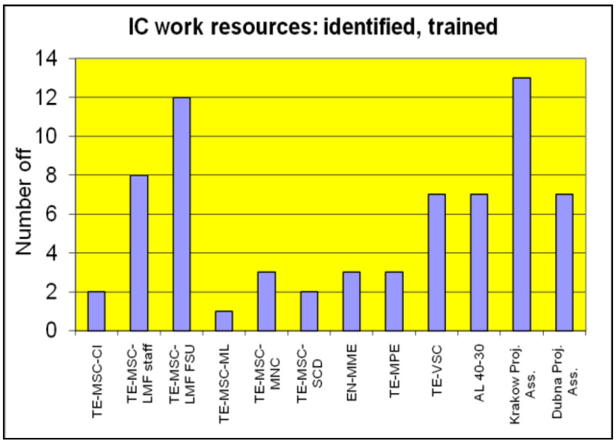

Figure 3: Group origin of experienced resources

For a minimum shutdown duration, we cannot account for an initial slower training and learning period in the tunnel under the real working conditions. The experienced resources are therefore the backbone of the magnet/interconnection shutdown team: they ensure coordination, control, guidance and quality. To maintain these for critical activities, the ratio of "newcomers" to "experienced" should not exceed 1-to-1. These are the considerations that limit the overall resources that can be envisaged to work on shutdown activities, and hence determine the duration of the desired volume of work.

During the year 2010 an important effort was made to identify other resources, inside and outside CERN. A further ~1/3 was identified, see Fig. 4, based on the important assumption that injectors will be stopped to free resources (who are also to be "free" from any injector maintenance). It was clearly easier to identify resources for activities of Quality Control, inspections, measurements, data analysis etc. than for mechanical work. With the exception of the Dubna DN200 team, it was not possible to identify within potential collaborating Institutes resources for mechanical work.

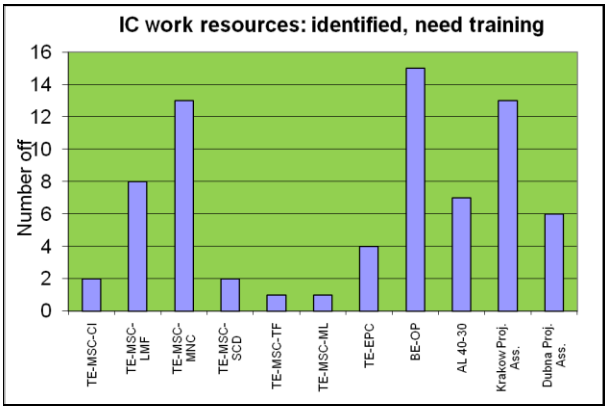

Figure 4: Group origin of identified resources needing training

The final ~1/3 of resources, mainly mechanics, is still not identified, with the only current option being employment of FSUs. It must be noted that for some critical activities, see Table 1 in yellow, the "healthy" ratio of 1-to-1 is not satisfied, implying an unacceptable increase in risk. To be stated clearly: after considerable efforts to identify suitable additional resources in 2010, we do not have the necessary experienced resources to perform the desired volume of work/quality/risk within a duration of 12 months.

Some mitigating options available in this planning stage are:

- increase duration of the long shutdown, specifically by 2-4 months. This would allow to shift valuable, experienced resources ending some "early" activities of the IC train to the SIT activities. With today's knowledge and uncertainties, the estimate of interconnection work duration is therefore minimum 14-16 months.
- lower the workload, specifically of the SIT (e.g. number of magnets to be replaced)
- early recruitment and integration of 5-10 FSUs in the coming months.

In addition to the interconnection work, significant activities need to take place after beam operation but before the first W bellows opening (electrical tests at cold, localisation of defects, warmup, leak testing, ... see [4]) estimated ~2 months. Similarly, significant activities will take place after the last W bellows closing (electrical tests, cool-down, hardware commissioning, ...) estimated ~3 months before beam on again [5]. The minimum shutdown time defined as "beam off-beam on" is therefore estimated 19-21 months.

Furthermore, the overall integration planning in the coming months will study the effects of coactivity between the different shutdown projects: IC train, SIT, DN200, R2E (e.g. effect of shielding installation at Point 5 blocking passage for 2 months, see [6]), collimators. This has a high likelihood to increase the above estimates of duration.

Activity	Identified, trained	Identified, but need training	Missing resources
Opening and closing W		8	20
Bellows inspection & protection, endoscopy beamlines	5	3	
Repair, reinstall & tack PIMs	incl.		2
Orbital machining M sleeves and PIMs	3	3	5
Busbar copper surfacing machining		7	
Electrical connections	8	9	3
QC electrical connections	4	14	
ELQA	13	10	
Leak testing	12	7	
TIG welding M sleeves and PIMs	6		9
QC Welding		2	4
QC closing W		4	
Other	5		5
DN200	7	1	
Special Intervention IC Team	7	4	9
Total	70	72	57
		199	
Note: resources at peak			
QPS	9	7	

Table 1: estimate of required resources for magnet/interconnections long shutdown activity (highlighted are critical activities lacking experienced resources)

A further effect of coactivity between some of these shutdown projects (magnets/interconnections and collimators) is a strain on the same experienced resources already today, namely for mechanical engineering, design, mechanics and welding. An urgent prioritisation among these – and indeed other projects (e.g. LINAC4, SPL, ...) – is advocated.

The work organisation structure for the magnets/interconnections activities is planned as previously to rely on three entities: technical work, Quality Control and tunnel coordination, see Fig. 5.

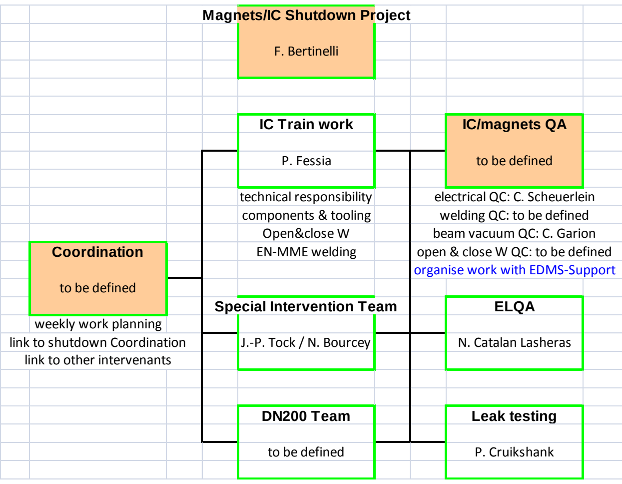

Figure 5: Magnets/interconnections organisation structure for the long shutdown

The overall budget for the magnets/interconnections long shutdown has been revised to 26 MCHF.

6 kA PRAYING-HANDS SPLICES

Considerable progress has been made in 2010:

- detailed electrical schematics showing number and type of splices;
- collection and review of existing documentation, specifically photos showing splices made in the tunnel;
- during the long shutdown, plan to perform partial inspections in some sectors where documentation is incomplete;
- mapping measurements in the tunnel of resistances at cold (segments of bus bars and splices in series) showing an average splice resistance of 1.14 nΩ and no outliers;
- the Quench Protection System will be upgraded to include these segments [7];
- fatigue testing at cold in Block4 of three samples in series: 12 000 cycles to 9 kA, then 12 000 cycles to 6 kA after introduction of a known defect. There was no deterioration of splice electrical resistance, and microscopic examination of the solder showed minimal crack initiation.

It was concluded that the current design can be maintained, this being endorsed by the First Splices Review.

OVERALL SPLICE RISK ASSESSMENT

The objective was to review full circuits, from current lead to current lead. Initial progress in 2010 was achieved in assessing the sextupole and octupole spool circuits. This work involves patient fact finding covering the corrector magnet production and testing, its integration with the dipole cold mass, testing at the Cold Mass Assemblers, testing upon reception at CERN, HWC, and experience with beam operation. These initial results show that the assessment inevitably extended from splices to general electrical and mechanical circuit aspects, specifically insulation, singular points (spiders), test and operation voltages. Also it became apparent that the assessment exercise was indeed fruitful and justified the new effort. Considering the difficulty in collecting the dispersed information, it also appears to be a unique opportunity to document and preserve it.

A further work consisted in performing an inventory of electromechanical singularities in the MB circuit.

To organise this work, mandate was given in September 2010 to H. Ten Kate / PH. Each circuit is being reviewed by an independent specialist, and then assessed by a group of magnet experts. This work is ongoing, aiming to reach final recommendations by May 2011.

CONCLUSIONS

Considerable progress has been made in 2010 on the design of the consolidated interconnection splice, on the 6 kA praying hands splices and on the general circuit risk assessment.

Progress has also been made in the organisation of the magnets/interconnections long shutdown, now based on a scenario with January 2013 as starting date. The bulk of IC work will be performed by an “IC Train”, non-standard operations by a Special Intervention Team. The overall resources needed are estimated at 200 persons.

One third of these is identified and experienced, several in collaborating Institutes or FSUs.

One third was identified internally at CERN and with collaborating Institutes during 2010 but will need training. This type of personnel will be used mainly for activities of quality control, inspections, data collection and analysis. It is important to clarify the conditions for injectors stop during this long shutdown since this has a big impact on the availability of these additional resources.

Finally the last third is still missing, needed mainly for mechanical work. It seems unrealistic after the 2010 efforts to expect these to come from collaborating Institutes. They will therefore be employed as FSUs, and it is recommended to start this recruitment early in order to start the integration and training process.

The ratio of 1-to-1 between experienced and newly introduced persons to ensure adequate work conditions in critical activities is currently not satisfied, thereby increasing the project risks.

By taking important assumptions on workload, tunnel work conditions and coactivity, it is estimated that the magnet/interconnection work alone will take minimum 14-16 months.

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[5] S. Baird, Summary Session 02 -03: Shutdown 2012, Chamonix 2011 Workshop.

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[7] Knud Dahlerup-Petersen , QPS Activities , Chamonix 2011 Workshop, Session 3.