EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 1122

THE LHC CONTINUOUS CRYOSTAT INTERCONNECTIONS: THE ORGANIZATION OF A LOGISTICALLY COMPLEX WORKSITE REQUIRING STRICT QUALITY STANDARDS AND HIGH OUTPUT

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Abstract

The interconnections of the Large Hadron Collider (LHC) continuous cryostat have been completed in fall 2007: 1695 interconnections magnet to magnet and 224 interconnections between the continuous cryostat and the cryogenic distribution line have been executed along the 27 km of the LHC. The very tight schedule, the complexity of the interconnection sequence, the strict quality standards applied have required the creation of an ad hoc organization in order to steer and coordinate the activities on the worksite dispersed along the whole accelerator ring. The concatenation of construction and test phases carried out by CERN staff, CERN collaborating institutes and contractors have led to the necessity of a common approach and of a very effective information flow. In this paper, after having recalled the main technical challenges, we review the organizational choices that have been taken and we briefly analyze the development of the worksite in term of allocated resources and production.

LHC-PROJECT-REPORT-1122
20 Aug 2008

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Presented at the 11th European Particle Accelerator Conference (EPAC'08)
23-27 June 2008, Genoa, Italy

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Geneva, 20 August 2008

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The interconnections of the Large Hadron Collider (LHC) continuous cryostat have been completed in fall 2007: 1695 interconnections magnet to magnet and 224 interconnections between the continuous cryostat and the cryogenic distribution line have been executed along the 27km of the LHC. The very tight schedule, the complexity of the interconnection sequence, the strict quality standards applied have required the creation of an ad hoc organization in order to steer and coordinate the activities on the worksite dispersed along the whole accelerator ring. The concatenation of construction and test phases carried out by CERN staff, CERN collaborating institutes and contractors have led to the necessity of a common approach and of a very effective information flow. In this paper, after having recalled the main technical challenges, we review the organizational choices that have been taken and we briefly analyze the development of the worksite in term of allocated resources and production.

INTRODUCTION

The LHC machine is divided in 8 sectors of about 3.2 km each; the continuous cryostat spans over 2.8 km between the 2 Arc Cryogenic Electrical Feedboxes units. Between these 2 units, 211 elements (210 in one sector) constitute the continuous cryostat section itself. These elements are 154 dipole magnet cold masses (4 different types of cold mass and 16 types of cryo-dipole), 55 quadrupole magnets cold masses (40 types of cold mass and 60 types of Short Straight Section) and 2 interconnection cryostats. In addition one in two quadrupole cryostats carries the extension (jumper) for the interconnection between the cryogenic feed line (QRL) and the cryogenic lines serving the magnets (28 interconnections per sector). To perform the total amount of 1919 interconnections (including jumpers) a competitive tender among possible industrial partners was issued and as result a contract was awarded to the IEG consortium. [1, 2]

MAIN ISSUES

The main issues and difficulties in organising such a worksite were identified to be:

- Geographical dispersion: up to 27 km of tunnel.
- Restricted access: each sector is accessible only from the access pits at its extremities; the limited diameter of the tunnel does not allow transport of material in parallel to work execution.
- Sequencing: the interconnection activity is divided in several phases which depend on the result of previous intermediary tests. Such tests are local (linked only to the work performed on the concerned interconnection) or extended (performed on a machine segment on which a previous assembly phase has been completed).
- Team coordination: the intervention of specialised teams dedicated to specific tests or actions needed to be actively and strictly coordinated to reduce co-activities, pursuing the highest efficiency.
- Non conformities: the declaration of non conformities, the following decision making process to identify the best applicable procedure, the problem solution and the consequent redeployment of teams to reduce time losses, needed a central management.
- Resource deployment, work load and resource forecast, planning, coordination with the previous installation LHC activities and the following commissioning activities needed to be done with a global view of the worksite.

TEAMS

The following teams were present on the worksite:

1. IEG (Ineo Endel Gti) interconnection team: its duty has been the execution of the largest part of the interconnection work where series production approach could be applied.
2. CERN specialised assembly team: composed by CERN engineers and technicians trained with them, it was in charge of special assembly procedures and of the repair of non conformities.
3. Quality teams: VAC (Vacuum team), ELQA (Electrical Quality Assurance) team, ICIT (Inter-Connection Inspection Team) team, CERN quality team, detailed description of their composition and activities can be found in [3]
4. CERN coordination team: composed by CERN staff, in charge of the coordination for all the different activities and teams.

COORDINATION

To take care of the previous issues and to coordinate the different actors an ad hoc team was formed with the duty to manage with a global vision the worksite. It was charged of the final responsibility for quality and technical decision and its duty was also to disseminate the necessary information to carry out the work. In this respect several tools were developed.

Workflow

A complete workflow diagram was developed and checked by all the concerned teams: interconnection, installation, alignment, integration, electrical test, vacuum test, quality control and all the other main activities and tests were introduced in the diagram. This complex workflow was the basis to build a common language among the different teams and to make them aware of their interfaces. It was the guideline on which the work sequence was established. The main point was not only the amount of activities done in one day, but the fact that a complete series of activities had to be performed in order to end an interconnection. A special attention was given in order to reduce as much as possible the dead times between operations on the same interconnection.

Follow up file

Following the workflow diagram, a detailed file containing the sequence of all activities was created. This file was specially formatted in such a way that the operations were released for work as soon as the laws imposed by the main workflow sequence were met. The file was filled almost in real time and made available online to all the actors. With this tool all coordinators could clear the work in a “just in time” way and the activities could be carried out optimising the time schedule. A summary file collecting all the information coming from the follow up files was used to draw a clear view of the work progression in each sector. Each file tracked 37 different assembly phases for each of the 211 interconnection for a total of 7800 assembly steps in one sector.

Mailing lists

In order to keep all the involved team informed 15 different dedicated mailing lists were created and used to communicate all the performed activities and the short term planning (more than 3.000 emails sent through the lists).

Coordination meeting

Once per week all the team leaders met: the midterm planning was discussed and the coordination team presented the work to be carried out day by day in the following week.

ORGANIZATION AND HISTORY

The interconnection activities started in sector 8-1 (May 2005) and 7-8 (November 2005) with a slow pace: the delay in the completion of the QRL had caused delay in the installation of the magnet. This prevented the intervening teams to start confronting themselves with the real work load. In January 2006 a third sector was started: 4-5. The necessity to prove the productivity rates of the interconnecting team was clear and it was decided to perform it in this sector, where enough magnets had been aligned providing a continuous chain of magnets to be interconnected. This short pilot run took place in February-March 2006 showing that 8 interconnections could be performed each week. Taking into account that the results had been achieved with a not optimised organization, it was a success. On this basis CERN and industrial partners prepared a plan to increase the productivity to 9 - 10 interconnections per week per team and to be able to operate with an overall worksite production of 35-40 interconnects per week. The increase in production was set for October 2006. The efforts were then concentrated in sector 7-8, this in order to:

- Eliminate co-activity in sector 8-1 and 4-5 while magnet installation was proceeding, providing to the transport vehicles the best operating conditions. This allowed preparing a consistent amount of work when interconnection would have re-started in those sectors.
- Test all assembly phases at least once in one sector, debugging procedures and tooling.
- Provide a full interconnected sector for cool down operation start up and hardware commissioning.

Sector 7-8 was successfully completely interconnected in November 2006. From that moment a new approach was implemented with a so called continuous interconnecting scheme. With this approach two interconnecting fronts started from sector 4-5, one propagating towards sector 3-4 and then 2-3 and 1-2 the other towards 5-6, 6-7 and joining its forces to the previous front in sector 1-2. Sector 8-1, was kept voluntarily separated from this organization and separately managed. Each front was organised in sub-teams specialised in a group of correlated assembly phases depending on the work carried out by a previous sub-team. With this approach the sub-teams were investing the sectors in subsequent waves and were moved from one sector to the next one in order to keep the overall output as high as possible. A detailed planning sector by sector was then laid out with the objective to complete the interconnection of a sector in 25 weeks with overall completion at the end of September 2007.

In September 2006 the CERN coordination team took its function, while CERN quality control team and the specialised assembly team were re-organised. The latter was in charge of dealing with all non standard assembly phases and non-conformities requiring a special procedure to be solved. This approach was applied whatever was the origin of the non conformity: element to be interconnected or assembly fault. On the basis of this approach the industrial interconnecting teams could concentrate their effort in pushing their productivity while the problem was solved by specialised technicians using ad-hoc tools and procedures.

The increase in interconnection resources took place beginning of November 2006 (See figure 1). The change in organization, the massive training that had been achieved in sector 7-8 and the possibility to work on a front of continuous interconnections available for work allowed increasing the productivity by the required 20%. Global production output increased because of the introduction of the new team approaching the 40 interconnects per week (See Figure 2 for the productivity related to electrical interconnection). With this approach the time necessary to complete the 1st series of assembly operations (main electrical interconnections and beam lines interconnection) was reduced from 24 weeks in sector 4-5 to an average of 10 weeks. As consequence on the 2nd half of June 2007 all the main electrical interconnections of the machine were completed with few exceptions delayed because of non conformities: 70 % of the machine had been electrically interconnected in 10 months. Figure 3 shows the evolution of the cost structure in arbitrary units; the Work Package related costs (activity paid on a basis of a forfeit price) become relevant from November 2006 showing that the change in work preparation and planification had allowed providing a consistent and stable quantity of series production tasks to be carried out. This also matches in time with the increase in production and productivity visible in figure 2.

As previously mentioned the foreseen time to complete one sector was 25 working weeks. Looking at how much time was necessary to complete 80% of the interconnect, it results that (excluding sector 7-8 8-1 and 4-5 that were interconnected with a different approach) the time necessary was 30 weeks for 5-6, 2-3 and 3-4 while 25 weeks were necessary for sector 6-7 and 1-2. The last 30 interconnects of each sector could take up to 2-3 months more in function of the issues blocking the advancement of the work. Relocating resources and applying ad hoc management for each of the encountered problem allowed to limit the final delay of the interconnect completion. The last interconnect was closed on 7th November 2007 with one and half month delay on a planning laid out more than 1 year before when no sector had been yet completed and the resources to complete the work were not yet at CERN.

CONCLUSION

The realisation of the LHC machine interconnections has been an example of complex worksite because of its logistic access problem, because of the number of specialised teams intervening, because of the strict and complex assembly workflow to be followed. The quality standards to be fulfilled and the imposed planning make this worksite unique. A good strategic approach minimising from the beginning major co-activity, the implementation of central coordination with a global view, the use of strong independent quality teams and of skilled and staffed teams to deal with the unexpected issues have been instrumental in rising production output and keeping the quality standards high. The management of the last 15% of interconnects per sector have been the more complex, also due to the non conformities that had to be solved, and again should not be administrated with the aim to reduce the local delay but taking into consideration the global worksite optimization.

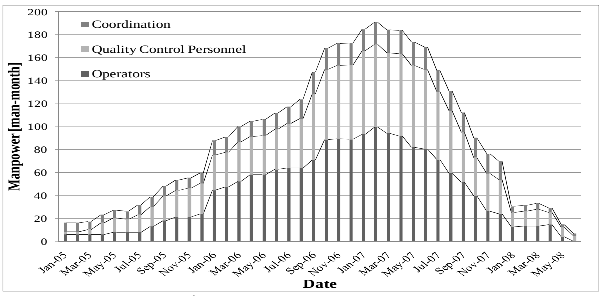

Figure 1: Evolution of personnel manpower working on interconnections divided by operators, quality control and coordination

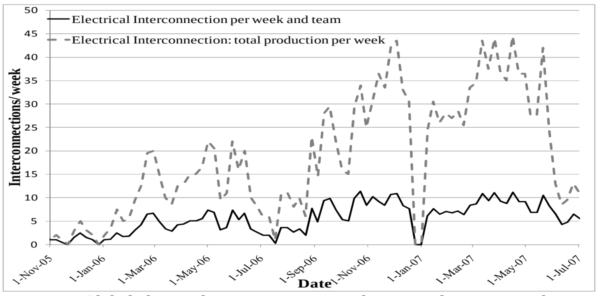

Figure 2: Global electrical interconnection production and average production per team between November 2005 and July 2007 (total 1695)

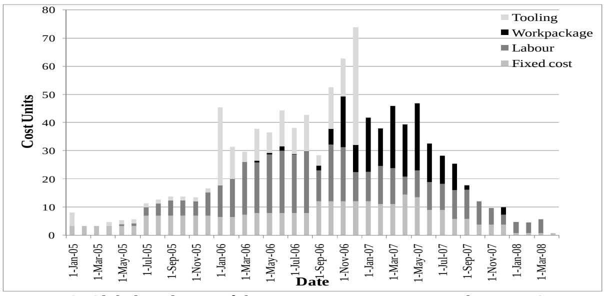

Figure 3: Global evolution of the cost structure in cost units between August 2005 and April 2008. Total invoiced costs normalised to 1000

ACKNOWLEDGMENTS

The authors wish to thank all the people working in the following sections at CERN: TS-CV, TS-EL, TS-IC, TS-MME, TS-SU, AT-CRG, and their colleagues of AT-MEI, AT-MCS and AT-VAC

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