THE ASSEMBLY OF THE LHC SHORT STRAIGHT SECTIONS (SSS) AT CERN: PROJECT STATUS AND LESSONS LEARNED

V.Parma, N.Bourcey, P.Campos, R.Feitor, M.Gandel, R.Lopez, M.Schmidlkofer, I.Slits,
CERN, Geneva, Switzerland

Abstract

The series production of the LHC SSS has started in the beginning of 2004 and is foreseen to last until end 2006. The production consists in the assembly of 474 cold masses housing superconducting quadrupoles and corrector magnets within their cryostats. 87 cold mass variants, resulting from various combinations of main quadrupole and corrector magnets, have to be assembled in 55 cryostat types, depending on the specific cryogenic and electrical powering schemes required by the collider topology. The assembly activity features the execution of more than 5 km of leak-tight welding of stainless steel and aluminium cryogenic lines, designed for 20-bar pressure, according to high qualification standards and undergoing severe QA inspections. Some 2500 leak detection tests, using He mass spectrometry, are required to check the tightness of the cryogenic circuits. Extensive electrical control work, to check the integrity of the magnet instrumentation and electrical circuits throughout the assembly of the SSS, is also carried out. This paper presents the current status of production, the assembly facilities at CERN, work organisation and Quality Assurance issues, and the acquired assembly experience after one and a half years of production.

INTRODUCTION

The design of the SSS was done by CERN in collaboration with the French institutes CEA and CNRS [1-3]. After validation on prototypes the series production was launched in Industry.

The manufacture of the SSS cold masses was contracted to one company, while the procurement of cryostat components and the assembly of the LHC SSS was contracted to another firm. Both companies were selected after competitive tendering in European industry.

Due to the insolvency of the latter at an early stage of the work the LHC project management decided in December 2003 that in order to avoid schedule slippage from re-tendering, the procurement of cryostat components and assembly of the SSS should be in-sourced at CERN.

CERN engineers had to re-establish a network of more than 10 major suppliers of cryostat components all over Europe, keeping the original suppliers of the former prime contractor, whenever possible, to gain time. Meanwhile the infrastructure and the specific assembly tooling had to be set up in a dedicated 2000 m^2 assembly hall at CERN (Figure 1). By amending a contract with a contractor already working at CERN, the assembly activity could be executed on the premises.

Figure 1: The SSS assembly hall at CERN.

WORK ORGANISATION AND STATUS

Procurement of components

The strategy of retaining the suppliers of the former assembly contractor without re-tendering was only partly successful. For the main component, the vacuum vessel, for which the lead time between tendering and initial production would have been the longest (not less than 1 year), retaining the initial supplier turned out to be the right choice. The supplier had already produced components at the time of in-sourcing and since then has been producing in advance on need for assembly and with the required quality. By offering to manage the storage of vessels at its premises and supplying regularly according to the needs, the firm relieved CERN from a cumbersome task of storage logistics. The former supplier of thermal shields made of aluminium extrusions encountered both technical and financial problems, constraining CERN to turn to another supplier producing similar components for the dipole cryostats. In a few other cases, the level of technical competency, in particular on welded assemblies for vacuum and cryogenic applications, was not up to expectations. Therefore, second lines of supply, at the cost of non competitive bids and additional project management effort, were to be found in order to ensure continuity in the assembly of the SSS. Components storage for such a large variety and quantity of components was also an underestimated task. Due to the lack of storage space in the surroundings of the assembly hall, components are stored in several remote places, with consequent handling and logistics difficulties.

Assembly of the SSS

The assembly of each SSS can be roughly split into three main steps: a) preparation of the cold mass with thermal shields and introduction into the vacuum vessel; b) mounting of the technical service module (QQS); c) final testing of the finished SSS. While the first and the last steps take about 2 days in total, mounting of the QQS takes between 2 to 3 weeks, depending on the complexity of the SSS type. 3 main categories of complexity have been defined: A for the simplest SSS, B and C for SSS of intermediate and high complexity respectively.

The degree of complexity depends essentially on the number of components to be mounted in the QQS (helium phase separator, cryogenic tubing, insulation vacuum barrier, etc.), the related welding work and associated leak detection. Welding is mostly done manually with frequent intermediate leak testing since, due to the intricate component integration in the QQS (Figure 2), most welds become inaccessible for repair at a later stage. Leak detection using helium mass spectrometry is extensively used for this purpose.

Figure 2: The QQS of a finished SSS.

At the end of assembly each SSS undergoes final testing, including global leak testing, electrical tests of magnets circuits and instrumentation and geometrical checks of interconnection interfaces.

Following an initial period of transfer of know-how from CERN to the contractor, the assembly of the SSS will be result oriented, the contractor being responsible for work execution, management of the required manpower and providing all standard tooling. CERN keeps responsibility for the infrastructure and the specific tooling, ensuring the availability of components, defining assembly technologies and procedures, and managing Quality Assurance. A CERN team dedicated to the engineering and QA was therefore set-up. Two service contracts for leak-detection and weld inspections were also established.

At present, some 40 people from the three contractors and a CERN team of some 10 people work in close collaboration: procurement engineers and QA inspectors, mechanical technicians, welders, crane operators, electricians, electro-mechanical technicians, vacuum technicians and weld inspectors.

The assembly of the SSS started in January 2004. After a difficult start up phase in the first months, the production rate progressively ramped up and has reached since 2 months a monthly rate of 20 SSS (Figure 3). 117 SSS have been assembled at this date, covering almost all the SSS types for the arcs.

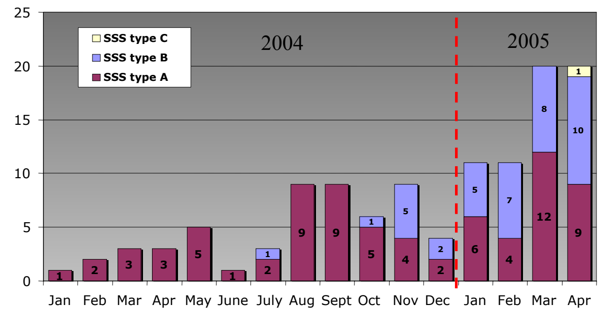

Figure 3: Monthly production of SSS.

Quality Assurance

The Assembly Breakdown Structure (ABS) documentation tells the contractor the sets of components he needs to use (tens of components or sets of parts in most cases). Detailed procedures per type of SSS guide the workers through the assembly cycle, enabling the contractor to organize the industrial production of SSS of a same kind. These documents include a number of hold points for intermediate tests or inspections (leak detections, weld inspections, electrical and geometrical checks) where CERN or its service contractors intervene for validation of the work. A detailed file for each assembly is completed for full traceability on production. Only a subset of this data, containing the final test results, relevant to the subsequent activities (cold electromagnetic testing, for example) and machine operation, are stored in a CERN database (MTF) to guarantee traceability and easy retrieval for future trouble-shooting.

Non Conformities (NC)

Figure 4 gives the break-down of the NC, by frequency and type, encountered in the first 16 months of assembly. 86 NC have been detected and treated during the assembly of the first 117 SSS. 67 % come from bad quality of components, whereas 33 % come from assembly problems.

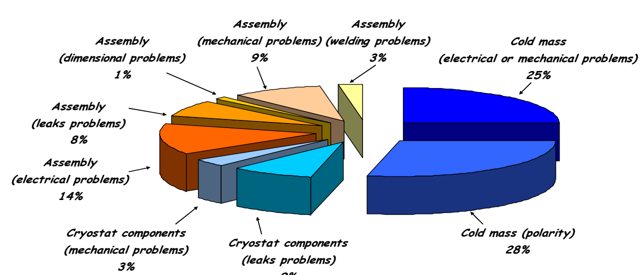

Figure 4: Break-down of NC on first 117 SSS.

Despite not being the most numerous, leaks are amongst the most time consuming NC to treat, particularly when localizing small leaks (~10-7 mbar/l/s).

0-7803-8859-3/05/$20.00

Because of high helium background from previous testing of cold masses made in industry, all subsequent welds made to it can only be tested by helium accumulation in pockets fitted around them while pressurising the cold mass with helium.

This test requires up to 15 hours during which no other assembly can be done. Whenever allowed by the geometry of the welds, helium accumulation tests have been replaced by faster leak-testing based on the hood clamshell method [5]. Alternative leak detection methods are also been considered to overcome the problem of low sensitivity of the detectors due to high helium background. The use of SF6, despite the cumbersome and expensive equipment for re-cycling this greenhouse effect gas, is presently under investigation at CERN and has already been successfully tested for leak detection on one SSS.

The most recurrent electrical NC detected on the very first cold masses were polarity errors from wrong routing or labelling of the corrector magnets bus-bars. To cope with this serious error, the SSS now go systematically through a final polarity check executed with a computer driven test set-up minimizing risk of human errors.

Up to date, about 5 SSS are affected by serious electrical NC (dielectric weakness in the corrector circuits), mainly experienced during electrical tests in cryogenic operation. Further investigation is needed but two SSS have already been dismounted and the cold masses will have to be disassembled for inspection. The use of reflectrometry with pulsed electrical signals for localization of dielectric weakness in the circuits is presently under development for diagnostics.

Non conforming components, not detected in industry, were assembled in the SSS and discovered during final leak testing. For one component, the origin of the flaw was traced back to a faulty heat of raw material used for making flanges. The consequences were severe, as about 50 SSS were assembled and three exhibited leaks which were difficult to repair. Investigation by a non destructive method using an eddy current device for detecting surface cracks was done on some 10 SSS in assembly, and one more potentially leaky flange was found. For the remaining SSS, which had all passed final leak testing, it was decided not to replace the component. The same investigation method was used to inspect the full batch of components before use. No defect was found.

However, the number of NC were reduced from 4 per SSS during the first 30 assemblies to less than 1 per SSS today, indicating a clear sign of improvement in the quality of components and learning in the assembly process.

LESSONS LEARNED

The slow start-up of the project is mainly imputable to the difficulties encountered with suppliers of components, re-organisation of the assembly hall to increase the number of assembly stands, coping with the too numerous NC on components or occurring during assembly, and the lengthy learning of the assembly process.

The effort for re-establishing a reliable network of cryostat component suppliers was underestimated. In a few cases, re-tendering on companies pre-selected through a market survey would have been more cost-effective and probably still acceptable schedule wise. The assembly time was also underestimated. The number of QQS assembly stands was insufficient especially in the presence of NC, and was recently almost doubled (15 stands), bringing the assembly hall to the limit of its capacity.

Electrical and leak-tightness NC exceeded expectations, seriously affecting the production flow due to the lengthy trouble shooting and repair work, and in a few cases leading to dismounting of the SSS. A dedicated structure is now being put in place for repair work of this type.

The assembly work requires skilled manpower, in particular welders and electricians, which the execution contractor is not always able to provide. Also, the elevated turnover of personnel requires continuous training of new personnel thus affecting overall work efficiency.

The complexity of in-sourcing of the SSS assembly was definitely underestimated; however, an encouraging learning process has been followed as proven by the increase in production rate and reduction in NC per SSS.

SUMMARY

Some 120 of the 474 SSS have been assembled at CERN in 16 months of production and the remaining 354 units require a production rate of 20 SSS/month to keep within schedule. The slow start-up of production was followed by a gradual ramp-up and in the last few months the nominal production rate is almost reached. The know-how transfer to the contractor is coming to an end and the number of NC per SSS is gradually reducing, confirming the benefits of the learning process. Though the activity is still far from completion, a solid project structure is now in place, with a motivated, competent and experienced team at work.

REFERENCES

[1] T.Tortschanoff and Al., "The Short Straight Sections for the LHC", PAC'97, Vancouver, 1997.

[2] J.C. Brunet and Al., "The New Superfluid Helium Cryostats For The Short Straight Sections Of The CERN Large Hadron Collider (LHC)", CEC/ICMC 1997, Portland, July 1997.

[3] L.Nielsen and AL. "A Modular Design For The 56 Variants Of The Short Straight Section In The Arcs Of The Large Hadron Collider", EPAC'02, Paris, June 2002.

[4] "Device for testing sealed integrity of a chamber (hood clamshell tool)", CERN Technology Transfer, https://oraweb.cern.ch/pls/ttdatabase/display.item?itemtable=patent&item_id=28