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LHC Superconducting Dipole Production Follow-up: Results of Audit on QA Aspects in Industry

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Abstract

The manufacturing of the 1232 Superconducting Main Dipoles for LHC is under way at three European Contractors: Alstom-Jeumont (Consortium), Ansaldo Superconduttori Genova and Babcock Noell Nuclear. The manufacturing is proceeding in a very satisfactory way and in March 2005 the mid production was achieved. To intercept eventually “weak points” of the production process still present and in order to make a check of the Quality Assurance and Control in place for the series production, an Audit action was launched by CERN during summer-fall 2004. Aspects like: completion of Production and Quality Assurance documentation, structure of QC Teams, traceability, calibration and maintenance for tooling, incoming components inspections, were checked during a total of seven visits at the five different production sites. The results of the Audit in terms of analysis of “systematic” and “random” problems encountered as well as corrective actions requested are presented.

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***Abstract*—The manufacturing of the 1232 Superconducting Main Dipoles for LHC is under way at three European Contractors: Alstom-Jeumont (Consortium), Ansaldo Superconduttori Genova and Babcock Noell Nuclear. The manufacturing is proceeding in a very satisfactory way and in March 2005 the mid production was achieved. To intercept eventually "weak points" of the production process still present and in order to make a check of the Quality Assurance and Control in place for the series production, an Audit action was launched by CERN during summer-fall 2004. Aspects like: completion of Production and Quality Assurance documentation, structure of QC Teams, traceability, calibration and maintenance for tooling, incoming components inspections, were checked during a total of seven visits at the five different production sites. The results of the Audit in terms of analysis of "systematic" and "random" problems encountered as well as corrective actions requested are presented.**

***Index Terms*—Mass Production of Accelerator Magnets, Quality Assurance, Quality Control, Superconducting dipole magnet.**

I. Introduction

The 1232 LHC Arc Dipoles are the main elements (in number and amount of materials operating in liquid helium at 1.9 K) of the LHC, the Large Hadron Collider, now under construction at CERN in Geneva – Switzerland [1],[2]. At present the mid-production milestone was passed and the total delivery is expected by end 2006 (Fig. 1 and [3]).

Following the March 2004 recommendation of the "LHC Superconducting Cable & Magnet Production Review" (an external international review board that is following at the rate of two meetings per year the superconducting cables and main magnet production), CERN decided to organize an "Audit on LHC Dipole cold masses (c.m.) Industrial Production" mainly dedicated to Quality Assurance (QA) and Quality Control (QC) aspects.

The major results of the Audit with main corrective actions asked to the Contractors are presented and commented below.

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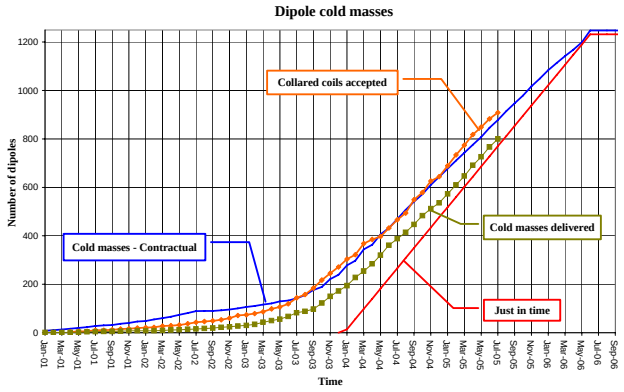

Fig. 1. Status of cold masses produced and delivered (from LHC Dashboard on CERN WEB page: http://lhc.web.cern.ch/lhc/)

II. Audit Organization

A. Scope and limitation of the AUDIT

First priority of the Audit was to check "how QC is implemented on the LHC c.m. production at all different production sites". The check of the technical details (correctness and completion) of the Manufacturing and Test Procedures was the second priority of the Audit. In fact, these technical checks and follow-up are also done via the daily actions of CERN Project Engineers and Technical Staff assigned to follow these Contracts.

The scope of the Audit was limited in the sense that it did not question the "general" QC system of the Companies; the audit action was focused on the LHC c.m. production QA/QC. When information about the general structure of the Companies was asked and presented, this was done to check the possible impact on the specific LHC dipole production quality.

B. Expected results from the AUDIT

By this action CERN was expecting:

1. To check that the QC Staff at each Cold Mass Assembler (CMA) production site is correctly sized and correctly acting concerning the LHC c.m. production.
2. To check the presence and correctness of all

Manufacturing, Testing and Inspection Procedures.

3. To check that the CERN technical specifications are correctly interpreted in the Internal Procedures of each company.

4. Finally, to detect possible erroneous application of the mentioned procedures, and through cross check of the QC procedures of the companies with CERN requirements, the presence of possible weak points in the QA of the production.

C. The Industrial Production Sites

As mentioned, the 1232 cold masses for the LHC are provided by three European Contractors: Alstom-Jeumont Consortium, Ansaldo Superconduttori Genova (ASG) and Babcock Noell Nuclear (BNN).

There are five different production sites:

a) Alstom-Jeumont Consortium have organized the production at their two sites as following:

- at Jeumont (F), Superconducting coils are wound, cured, and assembled in poles.
- at Belfort (F), the poles are assembled in dipole apertures and then, via the stainless steel collars, assembled in the collared coils. The cold mass is finally assembled around the collared coils.

b) ASG performs the full production at its premises in Genova (I).

c) BNN has organized the production in two sites:

- At Wurzburg (D) the magnet are assembled up to the collared coils stage
- At Zeitz (D) the “cold mass assembly” stage is performed before the final delivery of the completed cold masses to CERN.

D. Audit Committee and practical organization

The Audit Committee was composed by a selection of CERN project engineers assigned to the follow-up of the LHC main dipole cold mass procurements, and by some CERN colleagues from other groups and departments who are experts in specific domains like materials and metallurgy, superconducting magnet technology, logistics, and magnetic measurements and data analysis.

Due to the considerable amount of activities to be inspected, the Audit was organized in two phases:

Phase 1: Audit of the activities concerning the collared coils (i.e. components preparation; coil winding, coil curing, pole assembly, collars packing, collared coils pre-assembly and collaring)

Phase 2: Audit of the cold mass assembly activities (i.e. pole interconnections, iron-lamination packing, cold mass assembly, longitudinal welding of the shrinking cylinder, instrumentation assembly, geometric measurements, c.m. extremities assembly and alignment, final test, etc.).

For each phase, all the concerned production sites were visited. This means that in total 7 inspection visits were done.

All the visits were organized on a similar base:

- Half-a-day dedicated to a presentation by the Company about their internal QA organization and how this is implemented for the LHC magnet production;
- An exhaustive visit of the production site (at least one full-day);
- A debriefing between the Audit Committee and the Company Management on the first conclusions of the Audit.

The seven visits have taken place between July and November 2004.

III. RELEVANT AUDITING ASPECTS

Some common aspects regarding the QA on the assembly activities were defined a priori by the Audit Committee and attentively inspected during each visit:

A. Quality Assurance/Quality Control General Structure:

We were interested to have information and details about:

1. Manufacturing and Test procedures and QA Inspections: are all procedures present and correctly implemented at each working station (including the major technical requirements for the main sub-suppliers)?
2. The organization and manpower of QA/QC staff: how it is structured? Is the staff adequate in number and training? Is a back-up of the key positions available?
3. Treatment of Non Conformities and Change Notice: How should this be done and how is it applied in practice?

B. Incoming & Storing Components Organization and areas.

The LHC Main Dipole cold masses are assembled starting from components provided by CERN (the majority) but also with other important components procured under the responsibility of the Manufacturers (e.g. quench heaters, end spacers for the superconducting coils, etc.)

Inspection at the reception of the components and storing is an important issue of the QA/QC process.

C. Cleanness of the activities and cleaning condition of the workshops.

The cold mass assembly can be divided in clean and less clean operations (this division corresponds to the assembly of the collared coils and iron yoke/cold mass parts, respectively). Especially for the integrity of the collared coil assembly cleanness is a critical aspect. In fact, presence of contaminants (like small metallic chips or burrs) may damage irreversibly the electrical insulation of the coils and the quench heaters and have extremely dangerous consequences on the integrity and functioning of the magnets working at high current in liquid helium at 1.9 K.

Finally, for each visited site, a list of major positive and negative points was set up.

A first debriefing meeting with the Company’s Management was done at the conclusion of each visit. Official reports were later released and the majority of the companies have then discussed with CERN and taken corrective actions for all the points underlined by the Audit.

IV. Audit Results

The overall results of the Audit are presented in Table 1. The results are presented for four companies, having considered independently the companies Alstom and Jeumont,. In the present section, comments about the "systematic" and "random" problems detected are given in order to have a correct interpretation of the Table 1.

A. Quality Assurance/Quality Control General Structure:

The completeness of the QA Structure of the three companies was found in general correct (confirming what was stated during the Market Survey and Tendering phases), but in two cases it was found that no back-up for some staff "key positions" existed. Especially in one of the two cases (Company 2) this was evident since the concerned person was on sick leave since several weeks and the QA activities were clearly suffering from this.

A general systematic aspect revealed at all five manufacturing sites was the missing identification in the Manufacturing Follow-Up Documentation (MFD) of some minor tooling like the one utilized for the coil end surfacing (by resin) of the inner and outer layers (see Fig. 2). Similar minor tools are utilized all along the cold mass manufacturing (e.g. for the coil extremities surfacing, for layer interconnections, pole interconnections, busbar interconnections). Even if on different level between the companies, this tooling was not classified as critical regarding the magnet performances and so the identification (in case of the use of several identical sets of tooling) was not traced back in the MFD.

Fig. 2. Example of "minor tooling" for cold mass production.

Another systematic point detected at all manufacturing sites concerned the calibration (dimensional, thermal, electrical) of this minor tooling: in several cases we found that this calibration is done on a yearly base. Due to the high production rate and the severe consequences that bad calibration could have for the performance of the superconducting coils, CERN has requested to perform a calibration check for such tools every 3 months.

A positive point to remark is the use at one company (Company 1) of "Performance Indicators" all along the cold mass assembly phase. These indicators monitor the working times compared to baseline times, the number of problems appeared, etc. This gives a useful and immediate overview of the performance of the serial manufacturing activities.

The same company has independently developed a polarity test (tool and procedure) to check the correct connection of corrector magnets (sextupole and octu/decapole magnets) mounted at the extremities of the cold mass.

B. Incoming & Storing Components Organization and Areas.

The very high rate of the LHC Main dipoles production requires the management of an impressive amount of components.

In fact, each of the 3 Contractors produces and delivers to CERN between 2.5 and 3.5 cold masses per week, each one about 15 m long and weighing 28 tons.

Even for this aspect a significant difference was observed between the different companies and sites:

- In all companies the component storing areas are well defined and physically segregated from the assembly workshops. In 3 sites this physical delimitation between production and storing is always correctly preserved. In one case (Company 3) this was not the case and several boxes of components "ready to use" or "still to be inspected" were found also in the manufacturing areas. In the best case (Company 4), a flow chart reminding the functioning and hierarchy structure of the QC on the incoming inspections inside the storing and manufacturing areas, could easily be consulted. And the components were prepared in dedicated sets (one per cold mass).
- One company (Company 1) has decided to reduce to a minimum the "incoming inspection and checks" having negotiated more checks at the subcontractors' premises. Frequent meetings with subcontractors and the use of the mentioned "Performance Indicators" seem to guarantee a good control of the quality of the components.
- In all Companies (even if at different level) the checking and inspection of the Certificate of Conformity of some components can be improved, especially the stainless steel raw material certifications. In fact due to the ultra high vacuum application, critical for such material is not only the steel grade but also other aspects like the detailed chemical composition and the production technology. In two cases it was revealed that some cold mass supports and/or flanges were produced with stainless steel grades not conform to CERN technical specifications or not fully specified according to CERN requirements. Similarly, at Company 1 the welding procedure of some welding flares (between c.m. end cover and beam pipes) was found not correctly qualified. Immediate investigation and corrective actions were requested to the companies and special tests and risk evaluation for the affected c.m. was launched at CERN.
- Especially in one case (Company 3) we found that the reception inspections are not done in a unique and coherent way as regarding the type of inspection, the traceability of the element inspected and the classification of the inspection results (no record of the measured values but only a "good"/"no good" evaluation).

C. Cleanness of the activities and cleaning condition of the workshops.

As already mentioned, the dipole cold mass assembly activities can be divided in two main parts: collared coils manufacturing and cold mass manufacturing. The first part is the most delicate as concerning cleaning conditions: the cable insulation, the winding of the coil, the curing of the layers, the assembly of the layers in poles and poles in aperture with all the ancillary components (as the ground insulation, quench heaters, collars instrumentation cabling, etc.) must be done in very clean conditions. For such activities, the working conditions were specified in the CERN Technical Specification (e.g. wearing overshoes and gloves) and the environment conditions (e.g. temperature and humidity control, interdiction to perform dangerous operation like metal grinding and cutting in proximity, etc.). For the cold mass manufacturing less stringent cleanness conditions are requested. The four sites concerning the collared coils manufacturing activities have shown cleanness conditions going from excellent to sufficient. The use of gloves during coil winding is not always applied. The complaint is that the operation with gloves is not sufficiently precise.

The most variable aspect between different sites is the overall cleanness level of the workshops. This aspect is also directly linked to the degree of organization in the workshops.

As a general result the procedures and activities were better qualified and documented in all sites. The audit has certainly helped to identify few mistakes in procedures and materials and had certainly a fair share in the general improvement in the quality that we observed in the second part of the dipole manufacturing.

Fig.3. Excellent order and cleanness conditions at one Manufacturing premises (Company 4)

TABLE I: MAIN RESUME OF THE AUDIT RESULTS

	QA/QC GENERAL STRUCTURE (MANUFACTURING AND TEST PROCEDURES, STAFF ORGANIZATION, NC/CN)	***COMPONENTS INCOMING INSPECTIONS AND STORAGE***	***MANUFACTURING ACTIVITIES AND WORKSHOPS CLEANNESS LEVEL***	***OTHERS***
Company 1	Very good (1)	Very good	Good/Very good	(1) Use of Performance Indicators; development of extra test tool and procedure (+)
Company 2	Good (2)	Very good	Good	(2) QA Staff to be reinforced (-)
Company 3	Good (3)	Good (5)	Sufficient/Good	(3) Staff to be reinforced (-) (5) Availability and "knowledge" of CoC (-)
Company 4	Very good (4)	Very good	Very good	(4) Efficient documents for coils visual inspections (+)
Systematic problems:	1. Traceability and calibration of "minor assembly tooling" 2. "Knowledge and comprehension" of the Certificate of Conformities (especially for stainless steel procurement).			

V. CONCLUSION

As major results of the Audit on the QA aspects for the LHC Main Dipole series production we could say that the traceability and improvement of the calibration for some minor tooling was systematically asked to the three Contractors. Inspections at the 5 production sites have shown different level of quality for major aspects as: QA/QC structure and organization, quality in components reception inspections and storing, as well as cleanness condition of the workshops. The Assembly and testing procedures applied are in general complete and sound and respect what is asked by the CERN Technical Specification. Some systematic and specific weak points on QA Structure were found and corrected.

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