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PRESENT QUALITY ASSURANCE FOR THE LHC BEAM VACUUM SYSTEM AND ITS FUTURE IMPROVEMENT

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Abstract

During the Long Shutdown 1 (LS1), the LHC beam vacuum system was upgraded to minimize dynamic vacuum effects like stimulated desorption and beam-induced electron multipacting. A quality assurance plan was mandatory due to the demanding vacuum performance and the limited access to the equipment during the following operation period. Laboratory assessment tests and underground interventions were performed following well-defined and approved procedures. All vacuum related activities were documented and written reports stored in dedicated databases. Quality controls were performed to find mechanical, cabling and equipment functionality non-conformities. Possible issues were identified, classified and tracked in a non-conformity database for future corrective actions. This contribution give an overview of the quality assurance policy followed during the LS1 and the non-conformities reported after quality control. Possible future improvements are also discussed.

INTRODUCTION

The LHC beam vacuum system [1] has several interfaces with other LHC systems. Its performance and reliability are one of the key-factors for successful operation of the accelerator. Because of the limited access for maintenance during operation, any unsuspected issue can bring significant time delay and additional cost. Due to these requirements, a quality management was implemented as an important part of LHC beam vacuum upgrade during the LS1 period.

LHC BEAM VACUUM SYSTEM AND LS1 UPRGADE

The LHC beam vacuum system consists of beam pipes at cryogenic temperature in the superconducting magnets, mainly in the arcs (ARC), and the long straight sections (LSS) operating to the greatest extent at room temperature. The ARC beam vacuum represents 86% of the total 27 km and is divided into 8 arcs operating on 1.9 K at an operational pressure lower than 10^{-6} Pa.

The LSS beam vacuum represents the remaining 14% of the storage ring circumference and accommodates the 4 main LHC experiments. The LSS include in total 174 vacuum sectors operating at room temperature together with 84 cryogenics sectors, stand-alone magnets (SAM) and inner triplets, operating at 4.5 K and 1.9K, respectively. Ultrahigh vacuum in the LSS is achieved using NEG coated chambers, NEG cartridges and ion sputtering pumps. Common pressure in the LSS after NEG activation is lower than10^{-9} Pa.

LS1 Beam Vacuum System Upgrade

During the LS1 upgrade (2013 – 2015) [2] both ARC and LSS were vented to air in order to integrate engineering changes. The LHC beam vacuum system was upgraded from the point of view of safety, performance, and reliability to meet RUN 2 requirements with 13 TeV collisions in the centre of mass.

For the ARC beam vacuum the following activities were held:

- Installation of Plug-In-Modules (PIM) half-shell protection.
- Installation of rupture disc at all quadrupole magnets.
- Installation of penning gauges to selected quadrupole magnets.
- Repair of non-conform PIM.

For the LSS the following activities were conducted:

- Repair of RF bridges in 96 warm modules.
- Exchange of solenoids by NEG coated RF bridges.
- Installation of additional 400 l/s NEG cartridges.
- Installation of NEG cartridges at SAM cryogenics sectors.
- Installation of modified ion-pumps with integrated NEG cartridges.
- Installation of vacuum and NEG pilot sectors.
- Upgrade of the experimental areas in order to improve the vacuum performance and reduce background.
- Re-commissioning due to activities on other systems (collimation, injection, instrumentation etc.).

LHC QUALITY ASSURANCE PLAN

The LHC Quality Assurance Plan (QAP) [3] was introduced during the LHC project phase in order to implement a Total Quality Management System, based on defect prevention and continuous process improvement. Using the quality assurance guidelines [4], QAP defines a whole product lifecycle including data management systems CERN EDMS (Data Management System) and CERN MTF (Manufacturing and Testing Folder).

LHC QAP for the Beam Vacuum System

During the LS1, all LHC arcs and the 148 room temperature vacuum sectors were vented and re-commissioned. In parallel with the underground activities,

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almost 1100 new devices were tested and accepted at the surface laboratories for machine installation [5].

From the point of view of QAP the lifecycle process milestone for LHC beam vacuum components is the moment of installation. Based on this, two different lifecycle phases of a beam vacuum component were distinguished:

1. Pre-installation phase
   - Design acceptation (Design Approval Meeting).
   - Product lifecycle tracking in MTF.
   - LHC beam vacuum compatibility testing.
   - Non-conformity tracking according to QAP [6].
2. Installation phase
   - Component installation into LHC.
   - Vacuum NEG activation and sector re-commissioning.
   - Non-conformity tracking using LHC beam vacuum non-conformity tracking system.

LHC BEAM VACUUM NON-CONFORMITIES

According to the LHC QAP, the non-conformity is defined as a nonfulfillment of a specific requirement [6]. From the point of view of beam vacuum the non-conformity is any unforeseen issue affecting the overall performance of the LHC beam vacuum system. During the pre-installation phase, the issues were identified and tracked by the MTF. To identify and track existing installation issues, a LHC beam vacuum nonconformity tracking SharePoint was developed during the LS1.

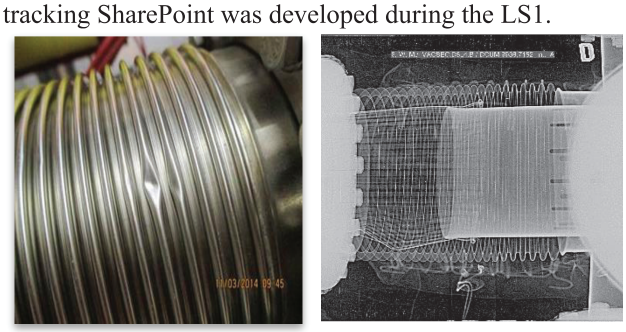

Figure 1: Typical LHC beam vacuum non-conformities.

Risk Assessment

After verification of a non-conformity existence, the issue classification was mandatory in order to identify its importance and disposition, which means that the issue is going to be repaired or stay use-as-is. In case of critical issue [3], nonfulfillment of a specific requirement may impair the ability of the equipment to achieve the needed performance or may affect safety of the system. To prevent this consequences a non-conformity meeting was held immediately to plan corrective actions. Otherwise the issue was classified as non-critical with disposition use-as-is and follow-up. Figure 1 shows typical non-critical (left) and critical (right) issues.

LS1 BEAM VACUUM CONSOLIDATION

A quality control team was established during Q2/2014 in order to check the LHC beam vacuum system for non-conformities. The way of working of the quality control team was procedurally defined based on previous experience from the LHC installation. Non-conform issues identified by the quality control team were mainly:

- Mechanical installation issues (missing equipment protection, grounding etc.).
- Equipment functionality issues (non-working gauges or pumps).
- Cabling issues (missing cabling of disconnected equipment).
- RF Bridges issues (beam induced heating [2]).

During LS1, more than 300 different non-conform issues were found. These were tracked by the SharePoint site. 21 issues were classified as critical and were repaired or scheduled for correction. About 80 non-critical issues were solved on the spot. The 177 remaining issues were classified use-as-is. Figure 2 shows the number of the non-conformity issues and their reduction in time thanks to the QC SharePoint handling.

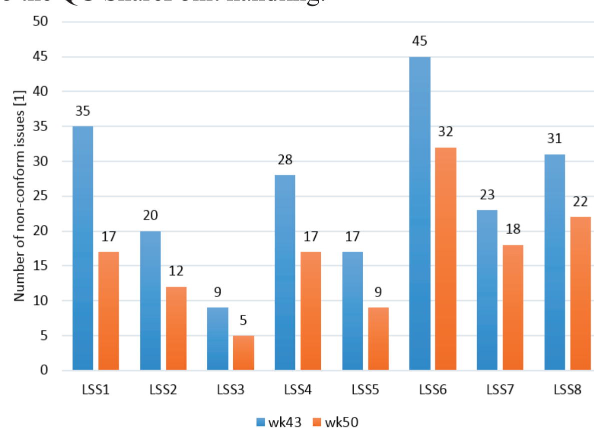

Figure 2: Number of beam vacuum non-conformities in start (wk43) to end (wk50) of QC machine tour.

X-Ray Campaign

Based on run 1 experience [2] and as a part of the quality control inspections, the quality control team performed length measurement for 99.3% of the LHC vacuum warm modules, which are equipped with bellows and RF fingers. Within this activity the length of 1812 vacuum warm modules was measured (12 modules were not accessible).

Figure 3 shows that most of the LHC vacuum warm modules are installed with minimum deviation from nominal length. As a condition for x-rays inspection, tolerance ± 5mm from nominal length was set. Based on this and the decision that experimental and recombination areas should be inspected without any exemptions, 809 modules were inspected by x-rays.

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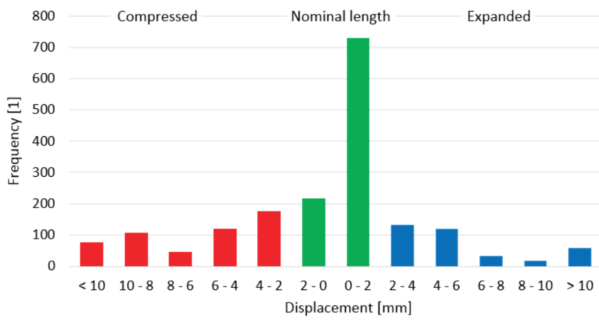

Figure 3: Length deviations of LHC warm modules.

The campaign revealed 69 non-conform issues. Using the non-conformity risk assessment, 17 issues were classified as critical and 6 selected for immediate repair. Disposition of the remaining 11 critical issues was set to use-as-is with foreseen correction during technical stops. 52 non-critical issues were accepted as use-as-is whereby 3 of these were repaired during the sectors opening.

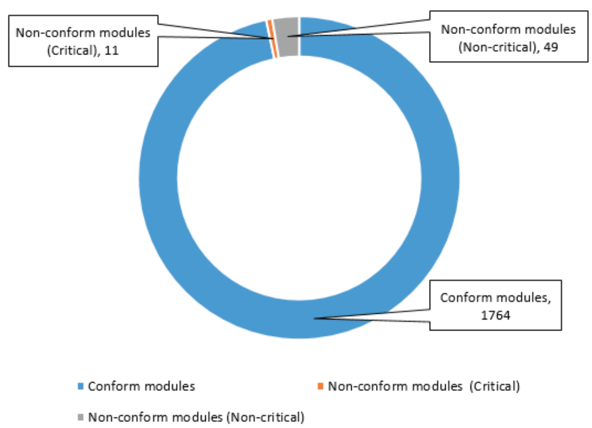

Figure 4: RF bridges non-conformity status after LS1.

After LS1, the status of RF bridges issues shown in figure 4 highlights that non-conform vacuum warm modules represents 3.3% of the total 1824 installed occurrences. Compared with non-conformities situation before LS1 (1800 modules, 96 issues) when 5.3% of LHC vacuum warm modules were found as non-conform (coarser x-rays tolerance +/- 10 mm) [2], the status after LS1 shows a significant-improvement due to more sensitive handling and better installation.

Based on the x-ray campaign data, the possible design, handling and installation issues were identified. Table 1 shows that the elliptic and rounded 66, 130 and 212.7 mm diameter RF bridges are the most difficult to install in conform state. Issues with 66 mm diameter bridge are located on cryo-side of sector valves assemblies. Root case of these issues is radial misalignment between module and magnet chamber. The larger diameter RF bridges (130 mm and 212.7 mm) are very sensitive to handling during the installation. This is mainly due to the high number of contact fingers and the position of a contact spring [7]. Positioning of the radial and axial offset needs to be considered for further tooling or procedural changes.

Table 1: RF Bridges NC

RF bridge diameter [mm]	Occurrences in LHC [1]	NC [1]	NC [%]
63	261	6	2.3
66	**29**	**4**	**13.8**
80	899	24	2.6
100	35	1	2.8
130	**42**	**4**	**9.5**
212.7	**71**	**5**	**7**
Elliptic 52/30	**100**	**6**	**6**
Elliptic 59/44	57	1	1.8
Elliptic 128/53	**24**	**6**	**25**

CONCLUSION

QAP plays an important role in the consolidation of the LHC beam vacuum system. Implementation of quality assurance in beam vacuum operation helps meet required vacuum performance of the LHC and minimize foreseen and unforeseen future interventions.

ACKNOWLEDGMENTS

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