

CERN VACUUM SYSTEM ACTIVITIES DURING THE LONG SHUTDOWN 1: THE LHC BEAM VACUUM

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Abstract

After the Long Shutdown 1 (LS1) and the consolidation of the magnet bus bars, the CERN Large Hadron Collider (LHC) will operate with nominal beam parameters. Larger beam energy, beam intensities and luminosity are expected. Despite the very good performance of the beam vacuum system during the 2010-12 physics run (Run 1), some particular areas require attention for repair, consolidation and upgrade.

Among the main activities, a large campaign aiming at the repair of the RF bridges of some vacuum modules is conducted. Moreover, consolidation of the cryogenic beam vacuum systems with burst disk for safety reasons is implemented. In addition, NEG cartridges, NEG coated inserts and new instruments for the vacuum system upgrade are installed. Besides these activities, repair, consolidation and upgrades of other beam equipment such as collimators, kickers and beam instrumentations are carried out.

In this paper, the motivation and the description for such activities, together with the expected beam vacuum performance after LS1, are described in detail.

INTRODUCTION

During Run 1, after a successful scrubbing period held during the beginning of 2011, the LHC beam vacuum system operated with a lifetime due to nuclear scattering of more than 2000 h. The LHC reached 75 % of the design proton luminosity at 8 TeV in the centre mass with 2×1378 bunches, spaced by 50 ns, each populated by $1.7 \cdot 10^{11}$ protons, and a total beam current of 2×420 mA. Among other great achievements, the total pressure inside the high luminosity experiments were kept below $3 \cdot 10^{-11}$ mbar with such beam parameters. This performance could be reached thanks to dedicated studies, designs, procurements, and validation tests prior to installation and commissioning in the LHC tunnel.

However, in order to prepare Run 2, several repairs, consolidation and upgrade are implemented during LS1. This paper will introduce these activities.

LHC ARCS

During LS1, all the LHC arcs were warmed up to room temperature (RT) to allow the consolidation of the magnet bus bars located at each magnet interconnects. In agreement with the recommendations of the tasks force following the sector 3-4 incident, all LHC Plug-In-Modules (PIM) are protected by two half shells to mitigate the impact onto the beam vacuum system of potential arcing. Moreover, a rupture disk was installed at each of the 850 arc's quadrupole to mitigate the bellows buckling along the beam line in case of He inrush. These

rupture disks are equipped with an innovative non-return valve which protects the cold beam vacuum system from air intake due to degradation with time of the rupture disks. Penning gauges were also installed into the arcs at specific quadrupoles magnets, Q12 and Q13. These vacuum gauges will reduce the pressure detection limit from 10^{-9} mbar to 10^{-11} mbar and, together with and upgraded cryogenic instrumentation, will allow a better monitoring of electron cloud at cryogenic temperature.

Beside these consolidations, regular activities were done. RF-ball test after warm up and before cool down were conducted to identify any buckled PIM. A total of 2 PIM were found buckled after warm up but, after the arcs consolidation, no PIM were found buckled prior to cool down. Identified critical non-conform PIM located mainly in the dispersion areas were also repaired together with others repaired during magnet exchanges. Helium leak tightness of the beam screen cooling capillary after several years of operation at cryogenic temperature was confirmed by monitoring the absence of He signal during warm up. Finally, all the cryogenic vacuum systems, *i.e.* arcs and standalone magnets (SAM), were evacuated during at least 5 weeks to maximise the removal of residual gas (mainly water vapour) prior to cool down.

LONG STRAIGHT SECTIONS

Despite the cumulated length represents only 14 % of the storage ring circumference, the long straight sections (LSS) contains 88 vacuum sectors at cryogenic temperature for a cumulated length of 1.4 km, and 174 vacuum sectors at room temperature (RT) for a cumulated length of 5.8 km. The room temperature vacuum system is fully baked; 85% of its surface is coated with 1- μ m thick TiZrV film, which provides most of the pumping speed.

During LS1, 148 room temperature vacuum sectors were opened and re-commissioned; this amount to 5.1 km of vacuum system to be re-baked. About 1/3 of the vacuum sectors was vented to air for vacuum related repair, consolidation, and upgrade. The remaining 2/3 was concerned by activities on other systems.

Vacuum System

During the rise of beam intensity in 2011, some RF bridges induced pressure spikes during physics fills as typically shown in Figure 1. These pressure spikes are due to beam induced sparking at RF bridges of the vacuum modules. As a consequence of these observations, a systematic X-ray analysis campaign of all 1800 vacuum modules was conducted during 2 years. The result of this campaign showed that 96 RF bridges were non-conform and distributes in 52 room temperature vacuum sectors.

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The systematic repair decided for LS1 requested the opening of 29 room temperature vacuum sectors.

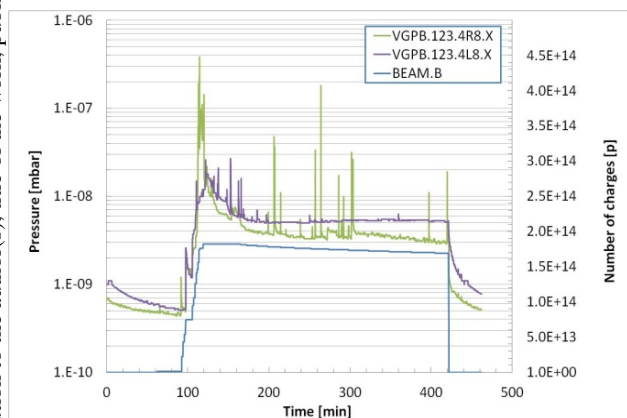


Figure 1: Typical pressure spikes observed in LSS 2 and LSS8 induced by sparking inside VAMTF modules.

Figure 2 shows typical RF bridge non-conformities (NC). On the left side, the NC implies a reduction of aperture with lose of RF contact. Its origin is due to a compression of the vacuum bellow VMAAF after installation, probably during bake-out. On the right side, the origin of the NC is due to beam induced heating as demonstrated by an X-ray image taken a couple of months before showing a conform module. A detailed analysis revealed a weak design which cannot tolerate misalignment in the vertical plane larger than one mm. This particular module type, VAMTF, has been removed from the vacuum layout.

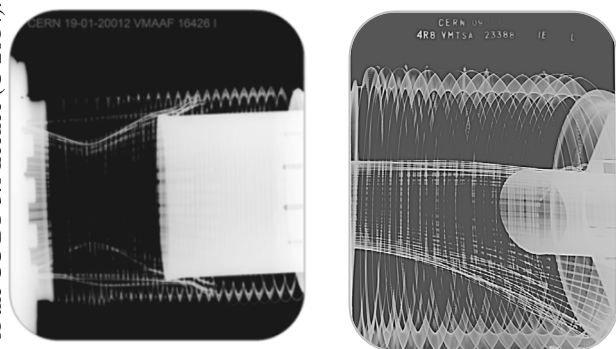


Figure 2: Typical RF bridges non-conformities.

During run 1 while decreasing progressively the bunch spacing from 150 ns to 25 ns, electron clouds showed up as expected. The preferred locations of electron cloud built-up are firstly unbaked room temperature two-beam pipes; then unbaked room temperature single-beam pipes; and finally all uncoated and baked vacuum chambers. Pressure rise was recorded in the different positions due to electron stimulated molecular desorption. In order to minimise the impact of pressure rises on the background of the experiments, it was decided to install solenoids in such locations during the winter technical stop 2010-11. 20 km of cables were wound around the affected vacuum chambers. The solenoids were powered ON during

physics fill and powered OFF during machine development to allow scrubbing of the vacuum chamber walls. In 2012, most of the solenoids were switched OFF with the exception of those on the injection kickers (MKI) areas. During LS1, in order to minimise the background to the experiment, the solenoids located in the room temperature areas are replaced by upgraded RF bridges made of NEG coated transition tubes; in addition, the local pumping speed is increased by a 400 l/s NEG cartridge complementing the 30 l/s ion pumps.

NEG cartridges were also installed in the cryogenic vacuum sectors of the SAM in order to pump the released gas during a magnet quench.

Finally, 88 400-l.s⁻¹ NEG cartridges were installed in the collimation areas (LSS3 and 7). The NEG cartridges will reduce the gas pumped on the NEG coating. Therefore, potential human intervention to re-activate the NEG coating during future runs will be avoided, in line with the ALARA principle. The NEG cartridges are inserted into modified standard-ion-pump vessels and placed at each collimator extremity. The possibility to remotely re-activate the NEG cartridges allows maintaining a sufficient pumping speed in case of large saturation of NEG coated beam pipes.

On the instrumentation side, dedicated vacuum pilot sectors for monitoring of NEG ageing, synchrotron radiation, and electron cloud were also installed in several vacuum sectors located in LSS 2, 7 and 8 [1].

Other System

Many types of equipment of other systems were repaired, consolidated and upgraded during LS1. In order to guarantee the vacuum performance, each device was previously validated in laboratory before installation into the tunnel. The validation consists in a bakeout cycle followed by leak detection, outgassing rate measurement, and residual gas analysis to identify the presence of possible virtual leaks and contaminants. A total of ~ 400 components were tested; Table collects the number of tests made for the different equipment's owners [2].

Table 1: Number of Test per Equipment's Owner (BI: Beam Instrumentation, ABT: Beam Transfer Devices, Alfa+Totem: Experiments)

	Collimation	BI	ABT	Alfa+Totem
Total	210	80	65	20

The LHC collimation system is made of 3 stages. The part of the second collimation stage is located in LS6 (TCSP). The whole third collimation stage is located in LSS1, 2, 5 and 8 (TCTP); it was upgraded during LS1. These TCSP with carbon fibre jaws and TCTP with tungsten jaws have embedded beam position monitors (BPM) to allow a faster and more accurate positioning during beam operation [3].

The LHC beam injection system was also upgraded, in particular the 8 MKI located in LSS 2 and 8. They had

their non-kicked Cu-beam-tube NEG coated and the impedance of the ceramic beam tube was further reduced by a modified beam screen [4]. In addition, 400 l/s NEG cartridges with NEG coated transition tube were installed between each MKI tank. Moreover, the BTV and BPM beam instrumentation (BI) equipment located upstream and downstream to the kicker magnets was NEG coated to reduce further the pressure increase during beam operation.

In LSS 6, the LHC dilution system was completed by adding a 5th diluter on the extraction line and the cold mass protection was upgraded by adding a third TCDQ mask on the beam line.

In LSS2 and 8, the injection mask (TDI) was upgraded following beam induced heating during Run 1 [5]. The mechanical rigidity of the beam screen was reinforced by changing its material from Cu to stainless steel. The sliding point mechanism was also upgraded with ZrO₂ bearings. The BN and Al masks were coated with a Ti thin film which allows reduction of the impedance of the secondary electron yield during beam scrubbing. The existing 400 l/s ion pumping system was consolidated with the addition of two 1000 l/s NEG cartridge. Finally, the TDI was sectorised by DN 250 gate valves to decouple the device from the neighbour sectors. This allows longer bakeout duration and local venting to exchange components during operational periods, if needed.

In LSS4, a RF module was exchanged by a new one. Several BI equipments such as beam position monitors (BPM), TV screens (BTV), beam gas injection systems (BGI), synchrotron light monitors (BSRT), wire scanners (BWS), and Schottky monitors (BQS) were also repaired and consolidated following virtual leaks, mechanical and beam induced heating issues [5]. The pumping scheme was also upgraded with 43 400 l/s NEG cartridge installed along the uncoated dampers beampipe (ADT).

Finally, 2 beam physics experiments were installed. A beam gas vertexing system (BGV) was installed in LSS 4 to monitor transverse beam profile; a crystal channelling experiments (LUA9) was installed in LSS7 to study future collimation schemes [6].

LHC EXPERIMENTS

All the vacuum chambers to be installed in LS1 into the cavern underwent vacuum acceptance tests in laboratory [7]. The main activity during LS1 was to exchange the Be beampipe at the interaction point of ATLAS and CMS. The new beampipes have reduced aperture: 47 mm instead of 54 mm in ATLAS and 43.4 mm instead of 58 mm in CMS. They allow accommodating more detector electronics close to the vertex. To minimise the induced radioactivity of beampipes, all stainless steel chambers in ATLAS were replaced by Al ones. In both experiments, the NC RF contact of the vacuum chambers at the TAS position were exchanged and upgraded by the addition of a NEG coated transition tube and a NEG cartridge.

In LHCb, a leaking Be chamber, UX85/3, was replaced providing, at the same time, room in the cavern to allow

detector maintenance. To avoid a complete dismounting of the vertex locator (VELO), the vacuum system was vented to neon. For this purpose, a special opening and closing procedures, which did not required a bake out of the VELO, were defined.

During Run 1, ALICE (an experiment dedicated to high-energy ion physics) suffered from background coming from LSS 2 during proton physics. For this reason, NEG coated liners were inserted into 800 mm diameter vacuum chambers to mitigate electron stimulated desorption induced by electron clouds generated by the two counter circulating beams.

Finally, NEG cartridges and NEG coated transition tubes were also installed from the VAX area in front of Q1 to the TAN/recombination areas of the LSS 1, 2, 5, and 8 to minimise background to the experiments.

CONCLUSION

Following a successful Run 1, the LHC stopped during about two years to allow repair, consolidation and upgrade of different systems. All the LHC arcs and 85 % of the LSS were vented to air to allow these activities. During Run 1, the LHC vacuum system baseline was proven to be valuable. Thus, the vacuum system was simply upgraded by adding more NEG coated surfaces and more pumping speed at identified weak positions. Dedicated instrumented areas were also implemented in order to provide a better monitoring of the LHC vacuum system performances.

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