LHC BEAM VACUUM DURING 2011 MACHINE OPERATION

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Abstract

During the year 2011 the LHC operated for 682 fills, meaning 247 days and 2 hours of stable beam in total. From 368 bunches per beam at 150 ns bunch spacing circulating in the ring in December 2010, the 2011 proton physic ended with 1380 bunches per beam circulating with 50 ns bunch spacing. The machine performances increased in parallel with the vacuum improvement thanks to a well performed scrubbing run in April 2011 and a continuous conditioning of the beam pipes while the machine was running. The 2011 LHC operation ended with one month of ions physic runs.

During the machine operation various phenomena of beam - vacuum interaction were detected, analyzed and solved. This paper describes the pressure behaviour along the machine layout and mainly in specific components position like the TDI (Target Dump Injection) and the MKI injector kickers. The "pressure spike" phenomena near the experiment CMS and in some Dipole 1 (D1) regions are discussed. Finally, results obtained during the 25 ns machine developments are presented.

INTRODUCTION

The LHC vacuum system, with its 48 km of cryogenic magnets and 6 km of room temperature vacuum system, which was designed to cope with beam dynamic effects, relies on cryopumping, NEG coating and lumped pumps. To achieve the accelerator ultimate performances, the *in-situ* beam pipe conditioning *i.e.* "beam scrubbing" was included in the machine set-up requirements.

Most of the room temperature elements of the machine, including the experimental beam pipes, but with the exception of magnet kickers (MKI), primary collimators (TCP), beam instrumentations equipments and some vacuum modules, are coated with Non Evaporable Getter (NEG) made of TiZrV. The NEG coated chambers provide the pumping speed all along the straight beam pipe. As complement, to remove the non-getterable gasses (noble gases and methane), 762 ion pumps are distributed along the LSS (Long Straight Sections).

To grant 100 hours of beam lifetime the pressure value should be kept below 1×10^{-8} mbar H_2 eq in the cryogenic beam pipe and 1×10^{-10} mbar on average in the LSS. Those values avoid excessive particle loss by nuclear scattering on the rest gas and grant a low background for the experiments [1].

The pressure rises detected during the LHC operation in 2011 are ascribed to three main phenomena: synchrotron radiation, electron cloud and heating effects.

Due to the centripetal acceleration of the bending magnets, the beams emit a synchrotron radiation that has a flat top spectrum energy which extends to a few 100 eV. The photon irradiation of the LHC beam pipe induces a source of gas that will always be present during the LHC lifetime.

Beam-induced electron multipacting can arise through an oscillatory motion of a cloud of photoelectrons and low energy secondary electrons bouncing back and forth between opposite walls of the vacuum chamber during successive passages of proton bunches. The interaction of this electron cloud with the vacuum surroundings stimulate the gas desorption. The electron cloud intensity is a strong function of the maximum secondary electron yield, δ_{max}, of the vacuum chamber walls. Recent estimation of the secondary electron yield (SEY) reached in the LHC and its multipacting threshold are given in reference [2].

Finally, some of the mechanisms that caused unwanted temperature increase and consequently pressure rise in LHC beam exposed equipments are proton losses and radio frequency field generated by the beam interacting with the beam coupling impedance of its surrounding equipment [3].

BEAM PIPE CONDITIONING

Thanks to the beam scrubbing at 75ns and 50ns, performed at the end of the 2010 LHC proton run, the 2011 LHC operation could start with 75ns bunch spacing beams. The year was then marked by a successful scrubbing run to prepare the machine for 50 ns operation [2].

Scrubbing Run

The LHC base line is the vacuum chamber conditioning under an electron bombardment that graphitise the exposed surface thereby reducing δ_{max} [4].

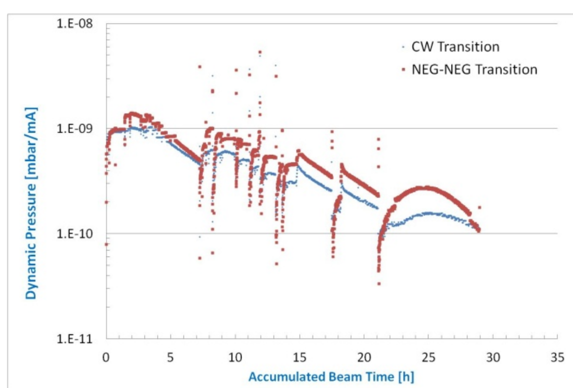

Figure 1: dynamic pressure increase in the Cold-Warm (CW) transition area and in the NEG-NEG area as a function of the beam accumulated time.

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The first vacuum observations of pressure rise had already been reported in 2010 with 150 and 50 ns beams and the hypothesis of electron cloud developing inside the beam pipe was confirmed by the heat load detected in the arcs and pressure rises of orders of magnitude larger than the base pressure.

The week 5-12 April 2011 was devoted to the scrubbing run with 50 ns beams. The aims of the scrubbing run were: (1) the reduction of the SEY in the arcs and straight sections to allow for operation with 50 ns beams with reasonable heat load, vacuum pressure rise and emittance blow-up, (2) to allow fast ramp up with 50 ns beams up to 1380 bunches, (3) to validate the strategy for suppression of e-cloud effect defined in the LHC Design Report [5].

During the scrubbing run, dynamic pressure increase due to electron cloud were observed all around the ring, with the exception of the NEG coated parts. Pressure rises that decreased with time were detected also in the arcs, corresponding to a heat load of maximum ~ 0.05 W/m [6]. At the end of the scrubbing run, a residual pressure rise was still observed in some cold-warm transitions and straight sections, while in the arcs both the heat load deposited onto the beam screen and the pressure increase went under the measurable range.

LHC Operation

Thanks to the scrubbing run and the expected beam conditioning of the vacuum system during the LHC operation for physic, the number of bunches circulating in the ring could rises up to the maximum value of 1380 bunches per beam. The peak luminosity was increased

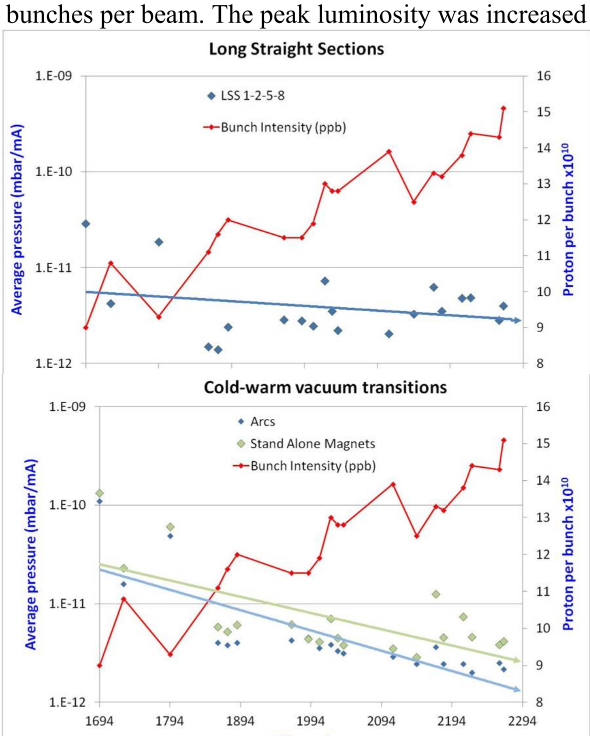

Figure 2: Overview of the average dynamic pressures in the LHC during the year 2011

reducing the beam size, squeezing the beams further and increasing the intensity per bunch up to 1.5×10^{11} ppb without globally any vacuum limitation. The average pressures decreased during the year in the range 10^{-9} mbar (Figure 2) while pushing the LHC performances.

It is worth to mention that the ion run at the end of 2011 did not suffer of any vacuum activities.

25 ns Machine Developments (MD)

Five MDs with 25ns bunch spacing beam were run from June to October 2011. During MDs with 25 ns beams, significant heat load up to ~ 0.5-1 W/m where observed in the LHC arcs. In the last MD, 2100 and 1020 bunches respectively for beam 1 and beam 2 were injected into the LHC ring.

DIFFERENT PHENOMENA OF BEAM VACUUM INTERACTION

All along the LHC 2011 operation, several pressure rises were observed in different position of the ring.

Beam Screens

Pressure spikes up to 10^{-6} mbar were observed for temperature oscillations in the 13-18 K range. These spikes were due to physisorbed hydrogen molecules desorbed from the beam screen's surface [6].

TDI, MKI and Collimators Pressure Rises

The increase of the number of bunches together with the bunch intensity enhances the beam induced heating in the near-beam equipments. The temperature increase is then the cause of the outgassing and pressure rise in the area around the heated component. In particular during 2011, several pressure rises were detected around different equipments such as the TDI protection device at injection, the MKI injector kickers and the TCP collimators in LSS7.

The TDI installed in LSS2 and 8 caused important pressure rise that, as confirmed lately by the thermocouples installed on the outer wall of the tank, had a clear signature of thermal heating. During operation, increasing the parking gap of the TDI jaws from +/-20mm to +/-55mm reduced the pressure increase, but not the temperature increase suggesting different sources of heating.

The MKI injection kickers showed significant pressure increase during operation. The worst case was the MKI-D in LSS8 that reached pressure value up to 1×10^{-9} mbar by the conjunction of electron cloud stimulated desorption and thermal outgassing. During the winter technical stop electron multipacting suppressor solenoids have been installed around all the interconnection tubes between the kicker tanks to slightly reduce the pressure rise and increasing a bit the margin for machine operation.

Finally the beam induced temperature increase on the TCP collimator jaws in LSS 7 obliged the relaxation of the temperature interlocks that were raised up to 70°C. The subsequent molecules desorption may causes, on the

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long term, the NEG coated chamber saturation and the increase of the overall sector ultimate pressure [7]. To preserve the NEG pumping efficiency in the area, the evaluation of the maximum acceptable working pressure during LHC operation is under study.

CMS RF Insert

During 2011 the CMS background suffered from pressure rise localized around the Interaction Point (IP). X-ray imaging of the forward module located at 18.3 m from the IP revealed a non-conformity in the RF insert, originated by a mispositioning of the secondary absorber target (TAS) chamber: the RF insert fingers overlap was shorter (6 mm) than the standard 13mm and some of the fingers were inside the beam vacuum chamber. The pressure spikes detected in that area were caused by arc ignitions between the detached fingers and the chamber while the overall pressure rise was certainly due to the RF insert overheating.

In January 2012, it was proposed to repair the RF insert under neon atmosphere [8] in order to avoid a full bake out of the CMS vacuum sector. The proposal was accepted by the CERN and CMS managements and the intervention was accomplished the 18th of January.

The neon injection method avoided the full bakeout of the CMS vacuum sector that would have required the opening of the entire detector and a five months extension of the winter technical stop. The CMS vacuum sector was pressurised at 1.2 bar to minimise the air backstreaming into the NEG chamber. The forward chamber was then disconnected and moved away to replace the damaged RF fingers under a constant neon flux. Once tighten back, the sector was pumped by a mobile pumping group located at Q1R5 to avoid the passage of air polluted gas through the IP. A pressure of 10^{-9} mbar was reached after two days of pumping thereby indicating that the NEG chambers were still active.

To check the NEG activation quality a test via transmission of hydrogen [9] between the module at 18m and the module at 13m, was performed using the NEG cartridges installed in the CMS right forward module. Comparing the results with the transmission simulation, it was verified that only 2m of the CT2 NEG coated chamber was saturated during the exchange of the RF insert, all the other chambers were still vacuum activated. The CMS forward chambers, together with the chamber located upstream and downstream, were then baked and re-activated to restore the initial pumping condition. At the end of the intervention the correct position of the RF fingers was double checked with X-ray radiography. The achieved pressures in the vacuum sector ended below 10^{-10} mbar and transmission measurements through the IP confirmed that the NEG vacuum chambers were correctly reactivated.

Vacuum RF Insert Modules

Other pressure spikes were observed beside the dipoles D1 in LSS2 and LSS8 (Figure 3). X-ray investigations revealed that the origin was a loosening of the spring that assures the RF continuity, keeping the RF insert fingers in contact with the chamber.

The four vacuum sectors (A4L2, A4R2, A4L8 and A4R8) containing these particular vacuum modules were opened for consolidation and layout modification. The RF bridges of the modules were fixed with a reinforcement sleeve around the RF fingers and the contact between the fingers and the insert was increased by bending the RF fingers towards the insert. These modules will be fully redesigned and replaced for the next long shutdown.

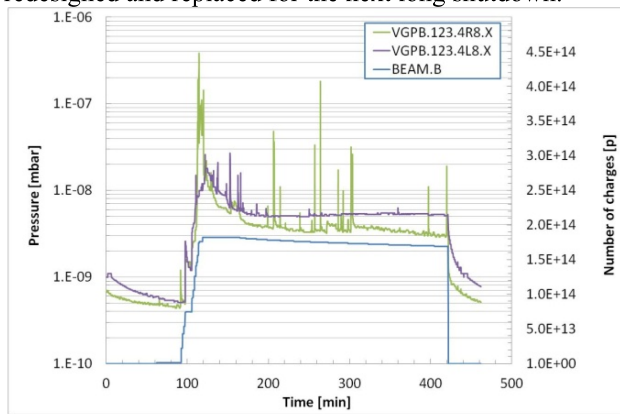

Figure 3: Pressure spikes on the vacuum RF insert modules.

CONCLUSIONS

The LHC vacuum performances in 2011 confirmed the sensitivity of the beam vacuum system to the machine parameters. During the winter technical stop several actions were taken to repair or mitigate the source of pressure rises. The machine conditioning and the reduced number of sectors opened during the winter technical stop allow a fast start up of the accelerator in 2012.

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