EVALUATION OF THE NEG COATING SATURATION LEVEL AFTER 3 YEARS OF LHC BEAM OPERATION

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Abstract

The room temperature vacuum system of the Large Hadron Collider (LHC) at CERN has been designed to ensure vacuum stability and beam lifetime of 100 h with nominal current of 0.56 A per beam at 7 TeV of energy. The requirements for the interaction regions are moreover driven to minimize the background noise of the experiments, to keep the equivalent hydrogen gas density below 10^{13} molecules of H_2 per m^3.

During the last two years, the LHC operated with proton beams at a maximum energy of 4 TeV, coasting for several hours each time, causing vacuum pressure increase owing to different effects: synchrotron radiation, electron cloud and localized temperature increase due to high order modes (HOMs).

All these phenomena liberated an important gas load from the vacuum chamber walls, which led in some cases to a partial or a total saturation of the NEG coating. To match the design vacuum performances and hence to schedule technical interventions for NEG vacuum reactivation, it is necessary to take into account all these aspects and to regularly evaluate the saturation level of the NEG coating.

This study analyses the saturation level of the NEG coated beam pipes in the LHC accelerator. Pressure reading variation of the Bayard-Alpert gauges without circulating proton beams are analysed and combined with laboratory studies of the NEG saturation behaviour. In addition, Vacuum Stability Code (VASCO) simulations are used to define the gas density profile change due to the saturation process in the NEG coated beam pipes.

INTRODUCTION

After an outstanding 2011 in which ~ 5.5 fb^{-1} of proton-proton collisions at 3.5 TeV were delivered to the two high luminosity experiments ATLAS and CMS, the 2012 run was intended to improve the reached performance. The beam energy, always with 50 ns bunch spacing, was increased up to 4 TeV and the target average bunch intensity was set at $\approx 1.60 \cdot 10^{+11}$ protons/bunch. With these parameters a final luminosity of ~ 23 fb^{-1} was delivered to both experiments.

The search for high luminosity brought operation in 2011 and 2012 to increase the beam brightness, thanks to the increase of the bunch intensity up to its limit. On the other hand, this also produced an increase of the dynamic vacuum mainly due to heating caused by the RF fields generated by the beam interacting with surrounding equipment [1], electron bombardments of the beam vacuum walls due to the formation of electron cloud [2] and synchrotron radiation effect [3]. Figure 1 shows an example of temperature rise of an injection kicker magnet (MKI) and of a primary collimator (TCP) during consecutives physics fills from May to June 2012.

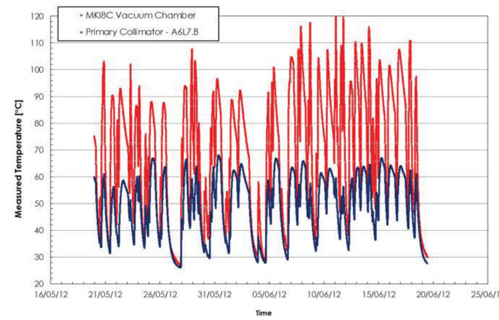

Figure 1: Typical temperature increase of the MKI8C and the TCP of vacuum sector A6L7.B during consecutives physics fills.

The room temperature vacuum system of the LHC Long Straight Sections (LSS), where these induced outgassing phenomena were observed, has been designed to ensure vacuum stability with an average pressure of 10^{-10} mbar with nominal current of 0.56 A per beam at 7 TeV of energy [4]. This is achieved by NEG coating on all walls of the vacuum beam pipes and a lump ion pumping system. After vacuum activation, NEG coating enables a distributed pumping speed all along the beam pipes with extremely low photon, electron and ion induced desorption yield. This assures low pressure increase even with high intensity proton beams. However, not all warm vacuum components could be NEG coated: all beam instrumentation and collimators, made of different metallic or ceramic materials, are uncoated so, an important source of outgassing.

SATURATION BEHAVIOUR OF NEG COATING

NEG coating is capable of pumping the gases present in UHV system, *i.e.* H_2, CO, CO_2, H_2O, plus N_2 and O_2 in the case of a leak [5]. However, it does not pump noble gases; for these and for CH_4, a limited number of sputter ion pumps are installed in each vacuum sector. The maximum distance between ion pumps is fixed at 28 m to avoid ion-induced pressure runaway. A reliable measurement at low pressure ($<10^{-10}$ mbar) is provided by a Bayard-Alpert gauge (BA) installed on the central portion of each vacuum sector.

On NEG surface, gases are adsorbed onto defined adsorption sites; each site may accommodate only one molecule and no desorption takes place. This is valid for all the gases pumped by NEG, besides H_2, which is not

ISBN 978-3-95450-122-9

chemisorbed but rather diffuse into the NEG bulk at room temperature. NEG is saturated when all adsorption sites are occupied.

Characterisation of beam pipes with saturated NEG coating was carried out on a LSS vacuum pilot sector at CERN [6]. The H_2 transmission method was used to test the effects of the saturation process [7]. Figure 2 shows the H_2 transmission factor, calculated by the pressure ratio between the injection position (BAstart) to the end of the beam pipe (BAend) during H_2 injection versus saturated length of the NEG coated beam pipe. It is worth noting that the quantity of gas seen at BAend remains constant even after more than 10 m of NEG coated beam pipe were saturated by a known amount of CO. This result clearly indicates that reading of the BA gauge at the end of the NEG pilot sector, and consequently of most BA gauges installed on each LSS vacuum sector, is just a local indication of the NEG performance; few meters of unsaturated NEG is able to keep pressure at the same level independently from saturation along the sectors.

In LHC, the length of the LSS vacuum sectors spans from a few meters up to a maximum of ≈ 155 m. Therefore, the quantification of the saturation level of the NEG coating results problematic due to the localized character of pressure indication of the BA gauge.

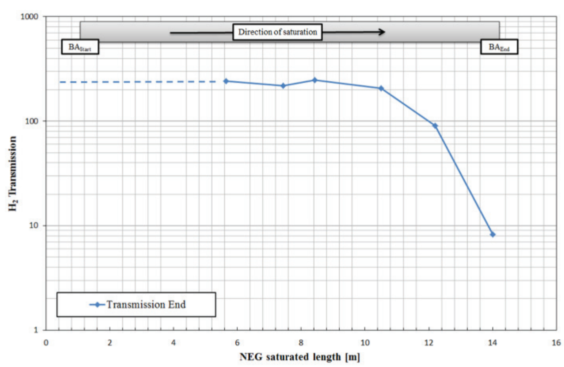

Figure 2: H_2 Transmission factor as a function of NEG saturated length for 14m vacuum beam pipe.

APPLICATION TO THE LSS

Before injecting the first beam in 2009, the average static pressure over 165 BA gauges in the LSS was $8.5 \cdot 10^{-12}$ mbar (N_2 eq.) after baking and vacuum activation of the NEG [8]. Figure 3 shows the increase of the static pressure readings of the BA over the last 3 years compared to their initial value. The reference pressure was taken 1 month after the first NEG vacuum activation. In order then to compare the pressure readings, all the BA pressures were also recorded at least 1 month after the last protons beam passed in the beam vacuum chambers, allowing time to recover and have a stable pressure reading. It is worth pointing out from Table 1 that about 72% of the gauges showed the same pressure reading in 2010 compared to their initial value in 2009. However, this number decreased to about 40% in 2011, falling to 25% in 2012. Moreover, at the end of the 2012 about 17 % of the BA gauges had recorded a pressure increase of more than10^{-10} mbar, indicating that a saturation process happened over the years.

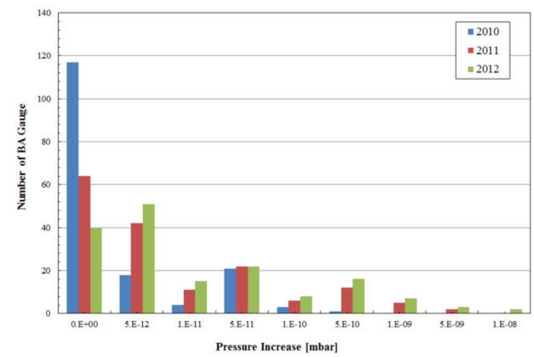

Figure 3: Static pressure increase recorded in the BA gauges over the last 3 years of beam operation.

Table 1: Percentage of BA static pressure increase over the last 3 years.

Year	≈ 0	< 1E-11	< 1E-10	< 1E-9	< 1E-8
2010	72 %	13 %	14.5 %	0.5 %	0 %
2011	39 %	32 %	17 %	11 %	1 %
2012	25 %	40 %	18 %	14 %	3 %

By analysing the position of these 17% of BA gauges (28 BA gauges), displaying a significant static pressure increase, it turns out that they are positioned mainly in 2 locations: LSS7 and LSS4. LSS7 contains the betatron collimation system of the LHC, with about 44 collimators or absorbers installed all along the ≈470 meter of the vacuum beam pipes. The LSS4 houses the radiofrequency cavities for proton acceleration. In LSS4, this static pressure increase is recorded in all vacuum sectors that accommodate beam instruments like beam wire scanners (BWS), beam synchrotron radiation telescope light extraction tanks (BSRT), beam gas profile monitors (BGI) and the transverse dampers (ADT). Another single vacuum sector that has over the years recorded a significant pressure increase is located in the LSS5. This particular vacuum sector of 20 m length houses a tertiary collimator with tungsten jaws (TCT) on one beam pipe and two TOTEM detectors (of Roman pot type) in the other. All these equipments installed between NEG coated beam pipes were source of important dynamic outgassing during high intensity beam operation. This is illustrated, for instance, by the fact that thermocouples installed in 2012 in the BSRT, recorded a temperature increase of up to ≈450°C during machine development fills [9].

VASCO code simulations are used to estimate the saturation process and analyse pressure profile along the vacuum sectors [10]. Three pressure profiles for static condition (*i.e.,* no protons beam) after NEG vacuum activation and after the 2011 and 2012 physics runs are presented in Figures 4, 5 and 6 for three different sectors of 20, 30 and 70 meters length, respectively. The graphs show that: pressure reading of the BA gauge is not a clear indication of the saturation extent of the NEG coating in the vacuum sector. The BA pressure level is mainly function of its distance from the degassing source, the ion pumps position and the extent of the saturation process; moreover, the saturation process is not uniform and constant along the vacuum sectors due to the difference sources of dynamic outgassing like in these examples, the active absorbers (TCLA), the TCT and the ADT.

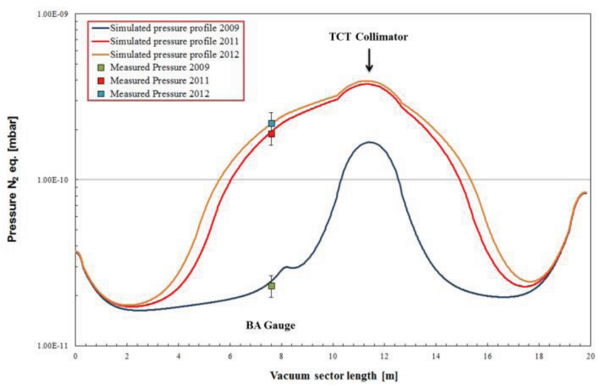

Figure 4: Example of static pressure increase in the vacuum sector A5R5.B.

SUMMARY

The saturation process of the NEG coating in the LSS during operation with high intensity protons beams is measured and analysed. In some areas of the LHC, a significant static pressure increase is observed as compared to the base pressure achieved in 2009 indicating that some parts of the NEG vacuum sectors result in being partially saturated. The different diameter of the vacuum beam pipes, the equipment's material and consequently the desorption yields and finally the length of the RT vacuum sectors are all parameters affecting the saturation process and the final pressure reading of the BA gauge. These diversities in the vacuum sectors, combined with the position of the BA gauges at variable distances from the possible source of gas, induces a degree of complexity in the analysis and the difficulty in defining a fixed rule for the saturation of the NEG coated beam pipes in the LSS. Each time, a increase of the base pressure in an LSS vacuum sector is recorded, a detailed analysis by simulation must be performed so as to define if a NEG vacuum activation of the vacuum sector must be scheduled.

The pressure profiles shown in Figures 4-6 in three different vacuum sectors analysed, which all feature a partial NEG saturation, show a pressure range from 10^{-10} to 10^{-9} mbar. This static pressure level is guaranteed by lumped pumping provided by the ion pumps and the still present pumping effect of the unsaturated NEG coating.

During the long shutdown foreseen in 2013-2014, most of the NEG coated vacuum sectors in the LSS will be re-activated and all possible sources of dynamic outgassing will be minimized with new design, new materials and/or new coatings. Additionally, new pumping equipments are foreseen to be installed in LSS7 so as to keep as low as possible pressure increase due to dynamic effects in the case of NEG saturation. Moreover, 6 dedicated NEG pilot sectors [8] will be installed in 3 different locations of the LSS, thus allowing the estimation of the NEG coating saturation process by the H_2 transmission method. These NEG pilot sectors will integrate 2 additional BA gauges each allowing more precise and distributed pressure reading.

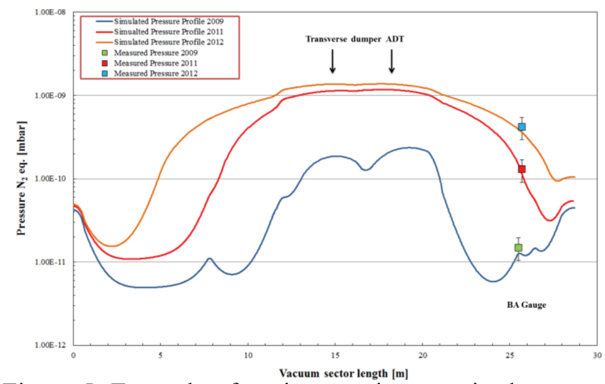

Figure 5: Example of static press increase in the vacuum sector B5L4.B.

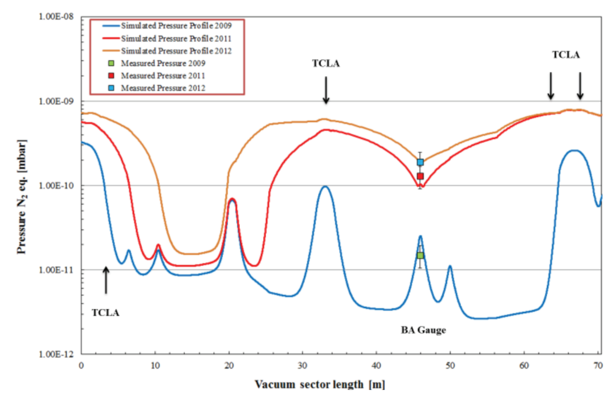

Figure 6: Example of static press increase in the vacuum sector A6R7.B.

ACKNOWLEDGEMENTS

To the formidable work of all the colleagues of the Vacuum Surface Coating group and in particular those of the LHC Beam Vacuum Section during these 3 years of operation is gratefully acknowledged.

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