OBSERVATIONS OF ELECTRON CLOUD EFFECTS WITH THE LHC VACUUM SYSTEM

G. Bregliozzi, V. Baglin, P. Chiggiato, P. Cruikshank, J.M. Jimenez, G. Lanza
European Organization for Nuclear Research (CERN), CH - 1211 Geneva 23

Abstract

In autumn 2010, during the LHC beam commissioning, electron-cloud effects producing pressure rise in common and single vacuum beam pipes, were observed. To understand the potential limitations for future operation, dedicated machine studies were performed with beams of 50 ns bunch spacing at energy of 450 GeV.

This paper summarizes the vacuum observations made during these periods. The effects of bunch intensity and different filling schemes on the vacuum levels are discussed. Simulations taking into account the effective pumping speed at the location of the vacuum gauge are introduced. As a consequence, the different vacuum levels observed along the LHC ring could be explained.

INTRODUCTION

Build up of electron cloud (EC) and electron multipacting was observed for the first time in the LHC with bunch spacing of 150 ns. The electrons, generated by the beam ionization of the residual gas were accelerated by the electric field of successive bunches towards the vacuum chamber wall [1-2]. The signature of electron cloud was a fast pressure increase due to electron stimulated desorption at specific location where unbaked stainless steel modules with copper RF shield constitute the connection between the room temperature and cryogenic sections.

In this paper, the observations made by dedicated study with LHC beam of 50 ns bunch spacing are shown with the pressure rise in different locations. In the second part, effects of the filling patterns parameters on the EC build-up are analyzed. Finally, results from a solenoid multipacting suppressor and from a dedicated scrubbing run are presented.

PRESSURE AT DIFFERENT LOCATION IN THE LHC

Figure 1 shows an averaged pressure increase for two different locations in the LHC during the injection of bunches with 50 ns bunch spacing.

At the first location, the vacuum gauge is installed on unbaked cold-warm transition (blue curve). The pumping speed is obtained by the NEG vacuum chambers (ϕ 80 mm) on its right and by the cold beam screen (ϕ 52 mm) installed on the left side. One ion pump is also present in the module. The length of the uncoated parts is about 1.3 m, see Figure 2, left side.

At the second location, the gauge is installed on a baked stainless steel module (green curve). The pumping speed is obtained by the NEG vacuum chambers (ϕ 80 mm) installed on both side. The length of the uncoated parts is about 0.3 m, see Figure 2, right side. The closest ion pump for this kind of vacuum gauge is installed at about 7 m far from it, and allows a maximum effective pumping speed for CH_4 of 10 L/s.

The VASCO code [3] was used to determine the gas composition at the level of these gauges as shown in Figure 2.

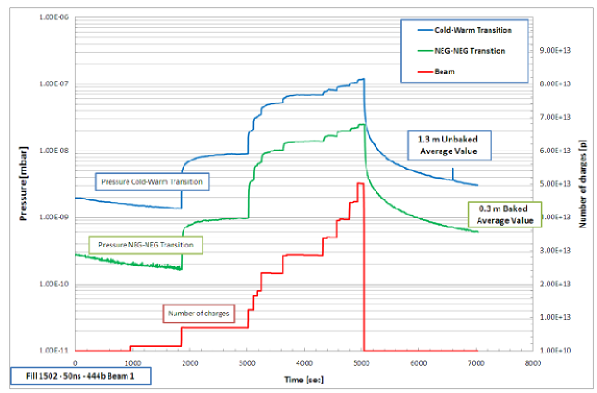

Figure 1: Pressure rise normalized to the beam current for different interesting area of the machine.

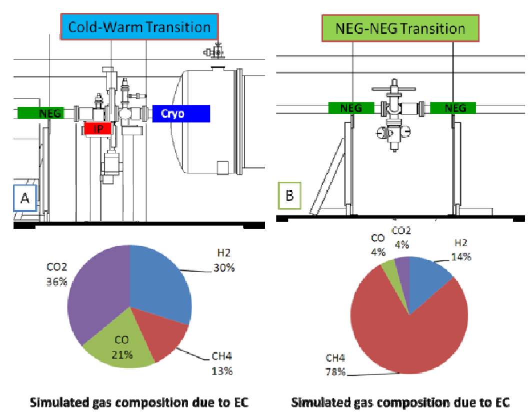

Figure 2: Sketch of the two locations analysed with the different pumping available at the level of the gauge (cryogenic, NEG and ion pumps) and with the estimated gas composition in presence of electron cloud.

The measured pressure increase due to the EC effect is dependent on the desorption yield (η), the electron flux ($\dot{\Gamma}$) and the effective pumping speed (S_{eff}) at the level of the pressure gauge, as indicated in (1).

$$P_{D1} \approx \frac{\eta_{Electrons}\,\dot{\Gamma}_{Electrons,}}{S_{eff}} \quad (1)$$

As shown in Figure 1, the pressure rise is neither uniform nor constant on these different areas of the machine. On the assumption that Γ́ is the same all along the beam pipes, the pressure variation recorded depends only on the different effective pumping speeds available at the port of the vacuum gauge and of the cleanliness of the surface.

BEAM EFFECTS

Bunch Intensity

Studies concerning the pressure dependence on beam intensity showed that it does not vary up to a bunch intensity threshold; above which, an increase in pressure was recorded (Figure 3). The data was taken for bunch spacing of 50 ns and injection of 12+36 bunches. The first 12 bunches do not contribute to the pressure increase. The data presented corresponds to a single beam vacuum and the combined effects of two beams on a merged chamber are not considered. The threshold is between 6 and $8{\cdot}10^{+10}$ p/b and is similar for the two transition.

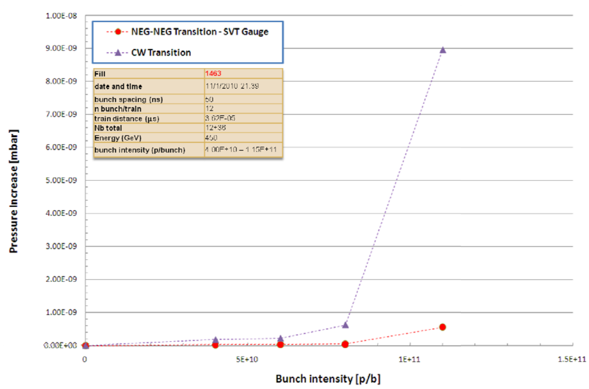

Figure 3: Pressure rise vs. proton bunch intensity for baked and unbaked vacuum module of the LHC machine.

Pressure versus Beam Current

Bunch trains (called batch) with bunch separation of 50 ns and bunch intensity of $1.2{\cdot}10^{+11}$ p/b were injected in the machine. Each batch was composed of 24 + 24 bunches with a constant distance of 1.85 μs.

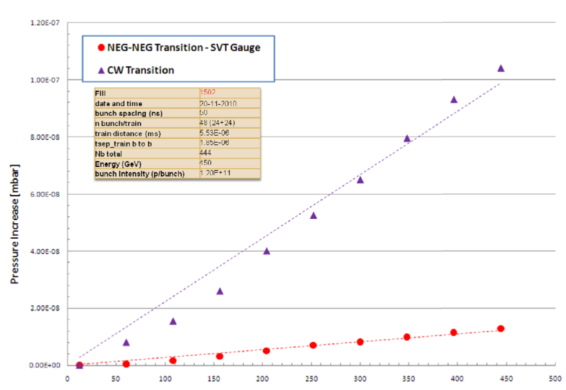

Figure 4: Pressure rise vs. number of bunches.

Figure 4 shows the pressure increase in the two locations analysed as a function of the number of bunches. A linear pressure increase was recorded each time a batch of 24 bunches was injected in the machine, indicating an EC activity linear with the beam current for each location. The results obtained by these tests allow the prediction of the number of bunches that could be injected with the same filing pattern in the LHC before reaching a pressure higher than $4{\cdot}10^{-7}$ mbar: the limit of the valves interlocks.

FILLING PATTERNS

Batch Separation

Bunches with constant bunch separation of 50 ns and bunch intensity of $1.1{\cdot}10^{+11}$ p/b were injected in the machine. Two batches of 24 bunches each, were injected, the distance between the two batches were adjusted and the pressure on different gauges was recorded. Figure 5 shows the average pressure rise for the two analysed positions. The batch separation time needed to enhance the EC activities was measured to be lower than 10 μs. With such batch spacing, two consecutive batches started to interact each other and were able to increase the EC phenomenon. Such a study allows also to constraint the surface parameters [4].

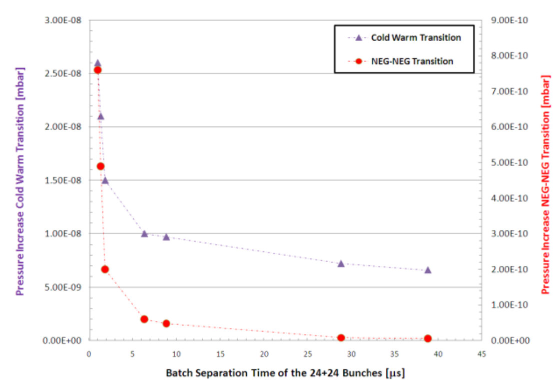

Figure 5: Pressure rise vs. batch separation. Tests were carried out to analyse the batch separation time for which the EC activity is enhanced.

Batch Population

In order to analyse and define the number of bunches needed to build up the EC, batches with 12, 24 and 36 bunches were injected in the machine. All batches were characterized by constant bunch separation of 50 ns and bunch intensity of $1.1{\cdot}10^{+11}$ p/b. Figure 6 shows the pressure increase in function of the batch population for a baked and an unbaked stainless steel vacuum module. A first batch of 12 bunches was injected and the distance between the bunch 12 and 13 was always kept higher than 10 us so as not to have any interaction from these two different batches. The results obtained allows a forecast of the number of bunches that could be injected in the LHC before reaching the vacuum interlock limit for a fixed filing pattern in the LHC.

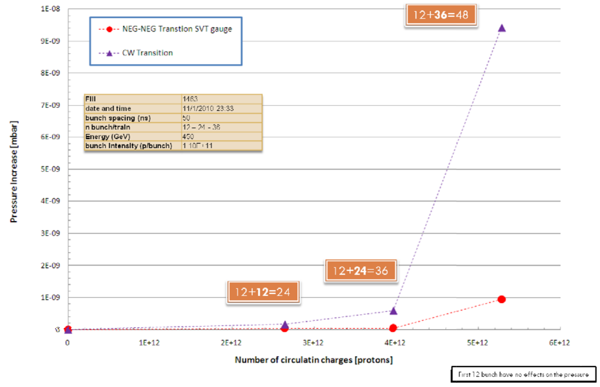

Figure 6: Pressure rise vs. number of circulating charges.

EC SUPPRESSOR AND CONDITIONING

Solenoids with a magnetic field of ~ 50 Gauss have been installed in all the cold warm transition of the LHC and are used during physic operation. Their role is to avoid multipacting in order to minimise the pressure increase stimulated by electron bombardments by confining the secondary electrons close to the wall's surface. As shown in Figure 7, when the solenoids are not powered, a pressure increase is recorded when nominal LHC beam is present in the machine; by applying the longitudinal magnetic field, a sudden drop in the pressure is clearly visible at both 450 and 3500 GeV.

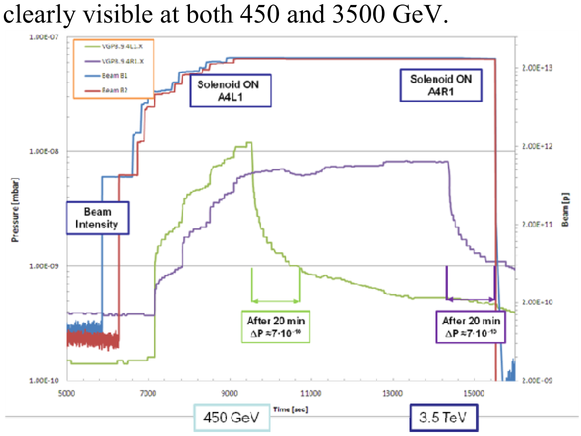

Figure 7: Effect of a longitudinal solenoid magnetic field of about 20 Gauss on the pressure rises in the LSS1 at 450 and 3500 GeV.

Vacuum cleaning and beam scrubbing is one of the principle mitigation for the electron multipacting problem. The vacuum cleaning is a dose effect due to the electron bombardments which produce a decrease of the electron desorption yield, η, and so the number of gas molecules desorbed from the surface of the beam vacuum pipe by the primary electron. The beam scrubbing is also a dose effect due to the electron bombardments but in that case produce a reduction of the secondary electron yield, δ, and so the number of secondary electron generated by the primary electron.

During a dedicated scrubbing run with 50 ns bunch spacing, clear evidence of vacuum cleaning was observed all around the machine. The decrease of the dynamic pressure function of the beam time of a cold warm transition is shown in Figure 8. After about 28h of vacuum cleaning and beam scrubbing, a decrease of one decade in the pressure was measured. Dedicated simulation study based on the recorded pressure data in the NEG-NEG transition showed that the δ has decreased from about 1.9 to roughly 1.7 during the scrubbing run [4,5].

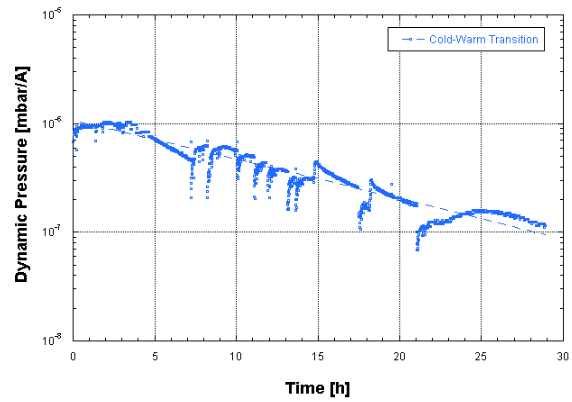

Figure 8: Dynamic pressure variation as a function the scrubbing time

CONCLUSIONS

A number of the electron cloud key parameters have been quantified by two dedicated machine developments studies carried out in the control room of the LHC. The effects of bunch intensity and different filling schemes on the vacuum activities have been analyzed. With 50 ns bunch spacing, electron cloud build up is occurring in baked and unbaked stainless steel modules housing the vacuum gauges. Simulations show and confirm that the different pressure increase recorded throughout most of the stainless steel modules is mainly related to the effective pumping speed at the location of the vacuum gauge.

Solenoid fields are effective to suppress electron multipacting, but at the same time prevent any scrubbing or vacuum cleaning. Scrubbing and vacuum cleaning are shown to effectively reduce the pressure increase induced by EC.

AKNOWLEDGMENTS

Many thank to our colleagues of the Vacuum Surface Coatings group and all the operators of the control room of the LHC.

REFERENCES

[1] F.Ruggiero et al., LHC Project Report 188, 1998.
[2] J.M. Jimenez et al., LHC Project Report 632, 2003.
[3] A. Rossi et al., LHC Project Report 674, 2003.
[4] O. Dominguez et al., these proceedings.
[5] G. Rumolo et al., these proceedings.