

# MEASUREMENT OF NEG COATING PERFORMANCE VARIATION IN THE LHC AFTER THE FIRST LONG SHUTDOWN

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## Abstract

During the Long Shutdown 1 (LS1) of the Large Hadron Collider, 90% of the Non-Evaporable Getter (NEG) coated beam pipes in the Long Straight Sections (LSS) were vented to undertake the planned upgrade and consolidation programmes. After each intervention, an additional bake-out and NEG activation were performed to reach the vacuum requirements. An analysis of the coating performance variation after the additional activation cycle has been carried out by using ultimate pressure and pressure build-up measurements. In addition, laboratory measurements have been carried out to mimic the LHC coated beam pipe behaviour. The experimental data have been compared with calculation obtained by Molflow+.

## INTRODUCTION

In February 2013, after three years of productive data collection, the LHC operation stopped for a 2-year-long shutdown (LS1) aiming at consolidating and upgrading the collider for 13 TeV centre-of-mass energy collisions.

During this period, all LHC arcs were warmed up to room temperature (RT) to allow the consolidation of the magnet bus-bars located at each magnet interconnects and, in parallel, a re-commissioning of the room temperature LSS [1].

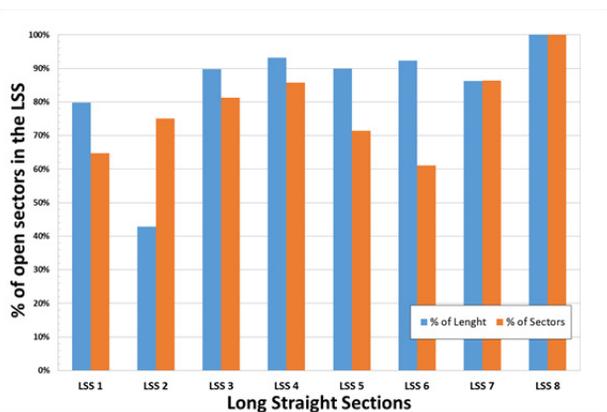


Figure 1: Percentage of open sectors during LS1.

The total length of the 8 LSS is 5.8 km which represents 14 % of the LHC ring length. By design, the LSS room temperature vacuum system is baked. About 85% of its surface is coated with 1- $\mu$ m thick TiZrV film which provides most of the pumping speed once activated. During LS1, 148 room temperature vacuum sectors (about 5.1 Km) were opened and re-commissioned [1].

Figure 1 shows the percentage of the vacuum sectors that were opened during LS1 in the 8 different LSS; most

of the sectors were vented. Afterwards, those sectors were baked and the NEG coating was activated.

Figure 2 shows the number of venting/activation cycles undergone by the vacuum sectors since their installation. About 80% of the NEG coated chambers had already been vented at least once before LS1. Possible detrimental effects on the vacuum performance of multiple venting/activation cycles were studied.

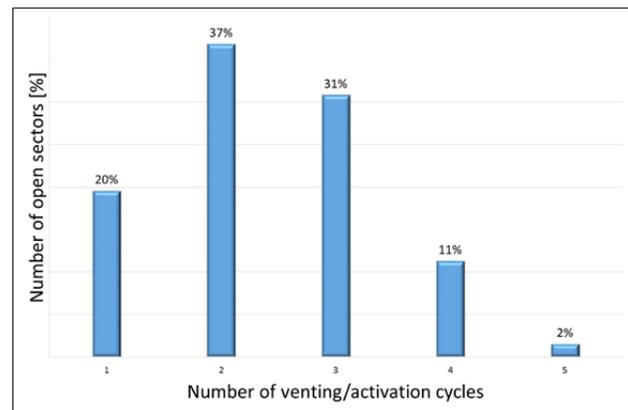


Figure 2: Distribution of baked sectors after LS1.

## PRESSURE DISTRIBUTION ANALYSIS

As a first step, the study focused on the ultimate pressure values measured in the LSS. All data were collected one month after the end of the NEG activation. All NEG activations were always performed at 230°C and lasted 20 to 24h.

The distributions (see Fig. 3) of the measured values after each cycle were then plotted in order to identify possible trends. For each distribution, a curve fitting was added and the statistical central values were indicated by arrows. A clear decreasing trend of the pressures after each venting / activation cycle can be seen. The statistical central value decreases by a factor 0.7 after each venting/activation cycle as calculated by linear regression. This behaviour is the result of the combination of two different phenomena described in [2]: in one hand, the decrease of the outgassing rate of the Bayard-Alpert gauges and of the stainless steel module and, on the other hand, the decrease of the pumping speed, i.e. the sticking probability, of the NEG coating after each cycle. The latter was measured in a dedicated experimental set-up.

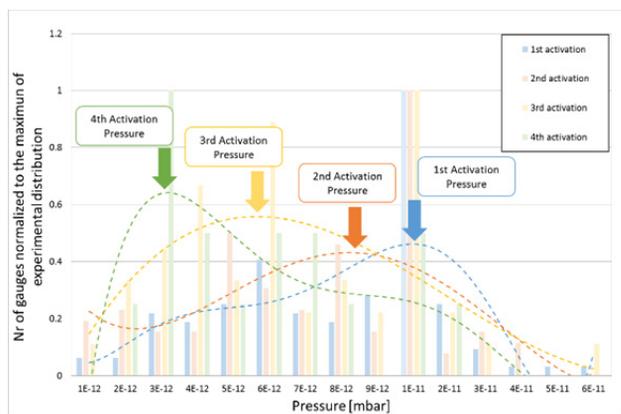


Figure 3: Pressure distribution one month after the end of the NEG activation.

### MEASUREMENT OF THE STICKING PROBABILITIES

Figure 4 shows the experimental setup adopted for the measurement of the sticking probabilities. It consists of three main parts: a pumping group, a Fischer-Mommsen dome, and the NEG coated vacuum chamber. The pumping group is made of a primary volumetric pump and a turbomolecular pump (TMP) that provides a nominal pumping speed of 250 l/s for N<sub>2</sub>. The TMP is connected to a Fischer-Mommsen dome [3]; the internal orifice of the dome has a diameter of 8.3 mm. The NEG-coated chamber is 216 cm long with a diameter of 80 mm. The total pressures, recorded by calibrated Bayard-Alpert (BA) gauges, were measured on both sides of the dome's orifice and at the extremity of the vacuum chamber. The partial pressures were measured by two calibrated Residual Gas Analysers.

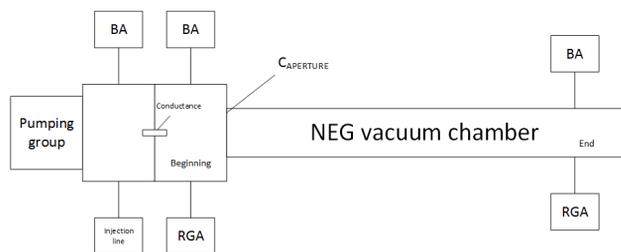


Figure 4: Schematic of the experimental setup. During gas injection, total and partial pressures are measured at both sides of the vacuum chamber. The outcomes of the experiment are the ratios of the pressures at the two extremities of the vacuum chamber, and the pumping speed of the vacuum chamber's aperture seen from the dome.

The stainless steel components, the measuring instruments, and the NEG chamber were baked for 24 hours at 250 °C, 350 °C and 120 °C, respectively. Then the NEG coated chamber was activated at 230 °C for 24 hours once the temperature of the stainless steel parts had been cooled to 150 °C.

After activation and complete cool-down, H<sub>2</sub>, N<sub>2</sub>, and CO were subsequently injected in the dome. The ratios of the pressure at the entrance on that at the extremity of the vacuum chamber were recorded. In addition, the pumping speed of the NEG-coated vacuum chamber's aperture was measured by the dome. After the measurement cycle the system was vented to N<sub>2</sub>-45 (99.995%, H<sub>2</sub>O<40 ppm, O<sub>2</sub><100 ppm) as in the LHC. The sequence venting-activation-measurement was repeated several times. The correlation between the pressure ratios and the sticking probability (*s*) was obtained by Monte Carlo simulation (Molflow+ [4]).

### RESULTS

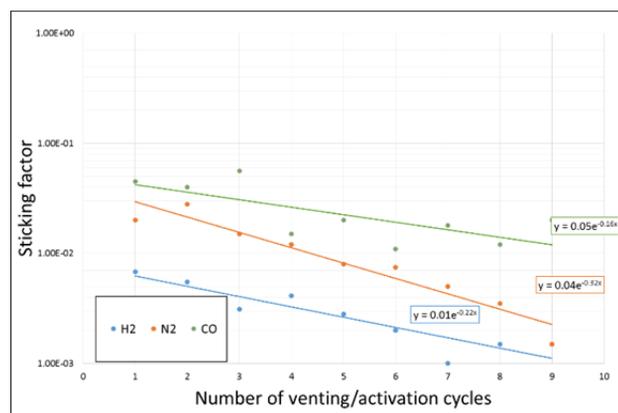


Figure 5: Sticking probabilities obtained by Molflow+ simulation from the total pressure ratio.

Figure 5 and 6 show the sticking probabilities for the three injected gas as a function of the number of NEG activation cycles obtained using the pressure ratios calculated from total and partial pressures, respectively. In both cases, a clear decrease of the sticking probabilities after each activation cycle can be seen.

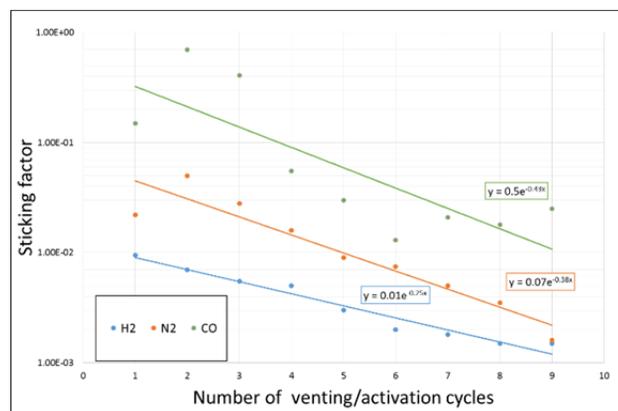


Figure 6: Sticking probabilities obtained by Molflow+ simulation from the partial pressure ratios of the injected gas.

In case of H<sub>2</sub>, the two curves of Fig. 5 and 6 are quite similar; this indicates that either total or partial pressure can be used for the sticking probability measurement.

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For N<sub>2</sub> the two curves appear slightly different. The difference is even more obvious in the case of CO, for which the ratio between the slopes of the curves differs by a factor of 2.

The discrepancy between the two curves is due to the free transmission of gas species that are not pumped by the NEG film, namely CH<sub>4</sub>, Ar and He. The rare gas can be a contamination in the injected gas. CH<sub>4</sub> can also be produced in the instruments, possibly due to the interaction with the hot filaments. The higher the sticking probability for the injected gas, the smaller the amount of that gas that reaches the end of the chamber. As a consequence, the non-pumped gas has an increased contribution to the total pressure reading at the extremity of the vacuum chamber and the total pressure ratio is not anymore correlated with the sticking probability of the injected gas (s is underestimated). This implies that for N<sub>2</sub> and CO the partial pressure ratio has to be used to evaluate the sticking probability.

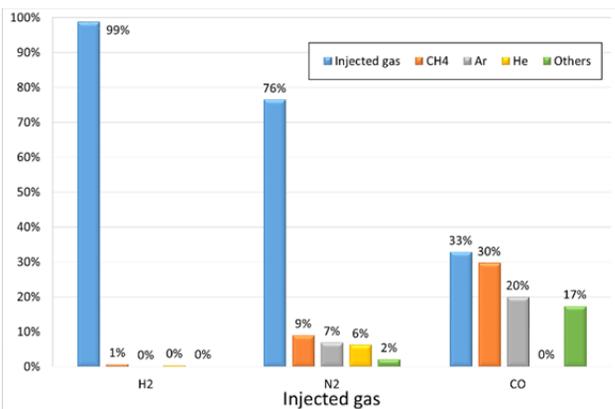


Figure 7: Gas composition as seen by RGA at the end of the chamber.

Figure 7 shows the average gas composition (percentage) at the extremity of the NEG coated chamber. As shown, during CO injection, only one third of the total pressure is originated from the injected gas.

Compared to previous measurements where the venting was performed with air, the reduction of the NEG sticking probability is much less [5].

Finally, in Fig. 8 the pumping speed of the chamber aperture seen by the dome as a function of the number of NEG activation cycles is shown.

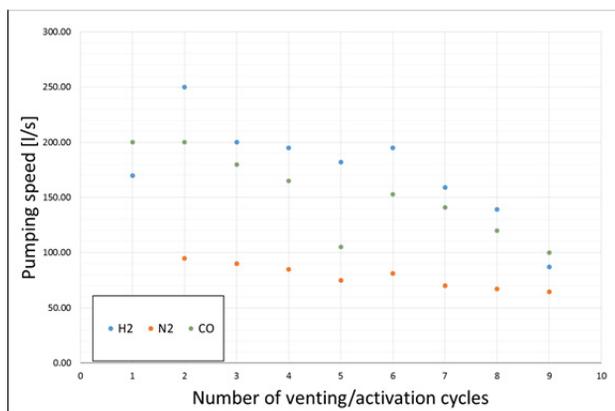


Figure 8: Pumping speed as a function of the number of venting/activation cycles. The aperture pumping speed decreases less than the sticking probability due to gas conductance limitation in the experimental set-up.

In the first 5 cycles the pumping speed of H<sub>2</sub> (the leading residual gas) can be considered roughly constant. As a consequence, the reduction of the ultimate pressure in the LSS can be ascribed to the decrease of the outgassing rate of the LSS modules where the BA gauges are installed. The outgassing rate should be reduced by about a factor of 0.7 after each bakeout. Such a result is in accordance with previous results and proves the diffusion nature of the hydrogen outgassing process [2].

## SUMMARY

The ultimate pressures measured in the LSS of the LHC improve after several N<sub>2</sub>-venting/activation cycles despite the reduction of the sticking probability. The improvement can be explained by a reduced local outgassing rate of the stainless steel modules where the pressure gauges are installed. The study has shown that the deterioration of the sticking probabilities is less pronounced when the NEG coated chamber is vented in regular N<sub>2</sub> than in ambient air.

## REFERENCES

- [1] V. Baglin *et al.*, "CERN Vacuum System Activities during the Long Shutdown 1: the LHC Beam Vacuum", WEPME047, proceedings of IPAC2014, Dresden, Germany.
- [2] P. Chiggiato, Vacuum Technology 1, JUAS 2014.
- [3] E. Fischer, H. Mommsen, Vacuum 17, 309 (1967).
- [4] R. Kersevan, J.-L. Pons, J.Vac. Sci. Technol. A 27, 1017 (2009).
- [5] P. Chiggiato, 45th IUVESTA Workshop on: Non Evaporable Getter (NEG) Coatings for Particle Accelerators and Vacuum System, 2006, Catania, Italy.