ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPME044

# LHC EXPERIMENTAL BEAM PIPE UPGRADE DURING LS1

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*Abstract*

The LHC experimental beam pipes are being improved during the ongoing Long Shutdown 1 (LS1). Several vacuum chambers have been tested and validated before their installation inside the detectors. The validation tests include: leak tightness, ultimate vacuum pressure, material outgassing rate, and residual gas composition. NEG coatings are assessed by sticking probability measurement with the help of Monte Carlo simulations.

In this paper the motivation for the beam pipe upgrade, the validation tests of the components and the results are presented and discussed.

## INTRODUCTION

After three years of productive operation, the LHC stopped for a 20-month period of maintenance (Long Shutdown 1) to perform all activities needed for a safe and reliable operation of the storage ring at nominal energy [1].

During such a period, the experiments, ALICE, ATLAS, CMS, and LHCb, have been making optimisations to their detectors, which include the integration of new vacuum chambers. The vacuum activities in the LHC experiments during LS1 are focused on the following points:

- Adapt the vacuum chamber to the new detector layout: e.g. change the radius of the beam pipe to add another layer of detector or change the chamber layout for mechanical reason [2].
- Reduce the screening for the detector: e.g. aluminium bellows have been developed in order to increase their transparency to radiation [3].
- Consolidation related to the safety of personnel: e.g. material exchange to reduce the radioactive activation of the vacuum chambers in regions of personnel intervention.
- Produce and have available one spare chamber for each new chamber of ATLAS and CMS, and for the already installed chamber of LHCb.
- The reliability and performance of each chamber was tested and validated before the installation. Since the vacuum beam pipes of the experiments are placed in the middle of the detector, inside several layer of complicated structures, it may take from one to six months to dismount a beam pipe placed inside a detector.

In the following paragraphs the details of the beam pipes validation tests are described.

## EXPERIMENTAL CHAMBER ACCEPTANCE CRITERIA

In the LHC's Long Straight Sections (LSS), including the experimental areas, the dynamic pressure should be less than $1 \times 10^{-10}$ mbar hydrogen equivalent [4]. This limit was set to reduce the background events in the detectors originating from the scattering collision process with the residual gas.

To achieve that vacuum requirement, all LSS's room-temperature beampipes, in particular those installed in the experiments, are internally coated with a Non-Evaporable Getter (NEG) thin film [5]. NEG are materials capable of chemically adsorbing gas molecules after heating to a temperature high enough to dissolve the native oxide layer into the bulk. At room temperature, NEG materials pump most of the gas species except rare gases and methane.

Experimental vacuum chambers can be heated from 180°C to 230°C depending on their material and mechanical characteristics. TiZrV getter was chosen because its activation can be obtained by heating at 180°C for 24 hours, therefore fulfilling the maximum heating temperature of all beampipes.

### *Acceptance Criteria before NEG Coating*

To avoid any contamination of the NEG thin film during the deposition process, the chamber cleanliness, leak tightness and absence of virtual leaks were verified before the coating procedure by residual gas. The following acceptance criteria were applied:

- Helium leak tightness: leaks above $1 \times 10^{-11}$ mbar l/s are not accepted.
- Material cleanliness: residual gas analysis is performed to exclude the presence of chemicals that can harm the NEG performance or influence the chamber base pressure. A clear explanation of the acceptance limits can be found in [6]. The same acceptance limits are applied to the NEG coated chambers as well.
- Outgassing rate: the hydrogen outgassing rate is measured and an acceptance threshold is applied.

### *Acceptance Criteria after NEG Coating*

The NEG coating performance is assessed by measurement of pressure during heating and sticking probabilities for hydrogen, nitrogen and carbon monoxide.

Based on previous studies of TiZrV NEG coating, the following test were performed for each vacuum chamber:

- Pressure follow-up during the NEG activation. The abrupt pressure decrease starting at 180ºC suggests a

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correct activation of the NEG coating as shown in Figure 2.

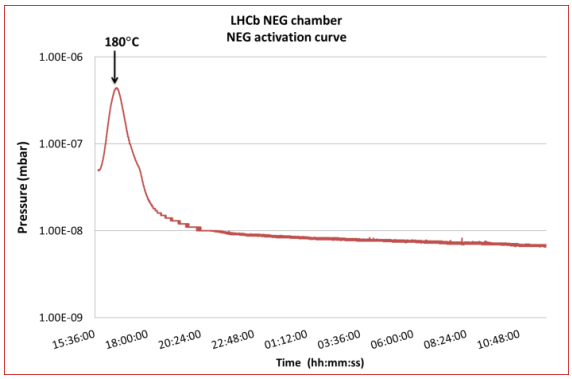


Figure 1: During bakeout, pressure decreases when the NEG chamber reaches the minimum activation temperature.

- Material cleanliness: residual gas analysis check.
- Measure of :
  - $H_2$ sticking probability: $1x10^{-3} < s(H_2) < 5x10^{-2}$ [7]
  - $N_2$ sticking probability: $s(N_2) > 1.5x10^{-2}$ [7]
  - CO sticking probability: $s(CO) > 7x10^{-2}$ [7,8].

## NEG TEST EXPERIMENTAL SETUP AND CALIBRATION CURVE

The sticking probability is obtained indirectly from the transmission ratio [9] and the beampipe-entrance-aperture pumping speed, by a calibration curve specific for each chamber geometry. Figure 2 shows the layout of the setup used for the measurements. Pressure $P_1$, $P_2$, and $P_3$ are measured by three Bayard-Alpert ionization gauges (CERN standard). An orifice of known conductance C is placed between the first two gauges; in front of the second one, a Residual Gas Analyser (RGA) monitors the gas composition in the vacuum system.

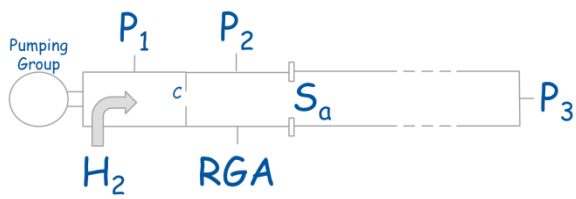


Figure 2: Experimental layout for the assessment of NEG coated chambers; the pumping group is a turbomolecular pumping unit. $S_a$ is the pumping speed measured at the entrance of the experimental beampipes.

Sampling gas is injected into the chamber and pressure rises are recorded. The transmission ratio T and the aperture pumping speeds $S_a$ are given by the following formula:

$$S_a = \frac{(\Delta P_1 - \Delta P_2)\cdot C}{\Delta P_2} \quad (1) \qquad T = \frac{\Delta P_2}{\Delta P_3} \quad (2)$$

T is the ratio of the pressure rises measured at the chamber extremities; it gives an indication of the NEG performance all along the beampipe. The aperture pumping speed is more related to the NEG performance in an area close to the flange.

Sticking probabilities are obtained from both experimental data by calibration curves calculated, for each beampipe geometry, by Test-Particle Monte-Carlo simulation. The TPMC software used at CERN is Molflow+ [9].

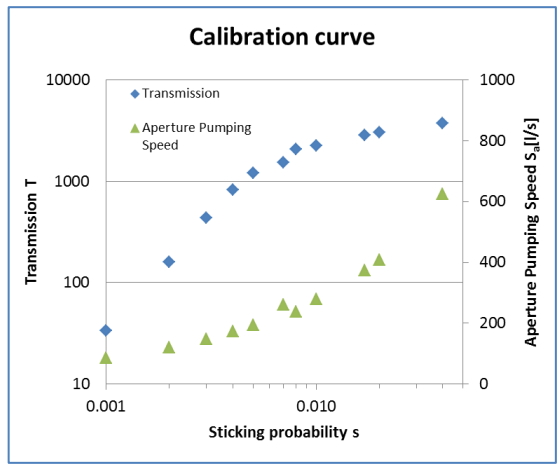


Figure 3: Typical calibration curve obtained by Molflow+ simulation.

## RESULTS

Gas contaminants such as $CH_4$, He and Ar are not pumped by the getter coating; they may heavily affect the indication of the gauge installed at the beampipe's extremity even if present at relatively low level. The main instrumental artefact is the production of $CH_4$ due to the cracking of hydrogen by the ionization gauges and the RGA's hot filaments. The contribution of the contaminants quantified by RGA calibrated spectra was subtracted to the $P_3$ readings.

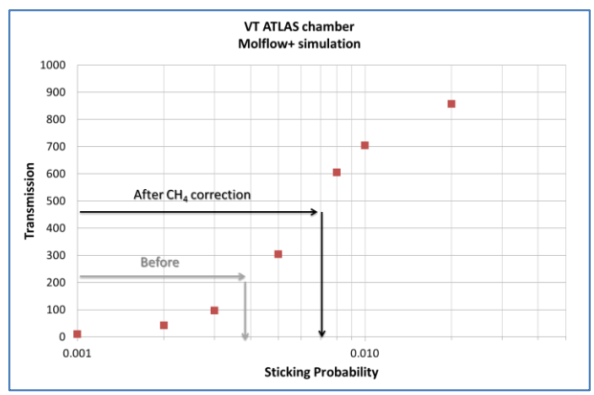


Figure 4: Correction of the transmission ratio: the $CH_4$ partial pressure rise is subtracted to the $P_3$ readings.

The source of noble gases might be the gas bottle itself but it's not confirmed by the gas purity certificate.

When injecting CO, the $P_3$ reading should be corrected for the $CH_4$ and $C_2H_6$ partial pressures rises. After correction, the corresponding measured sticking coefficient results higher.

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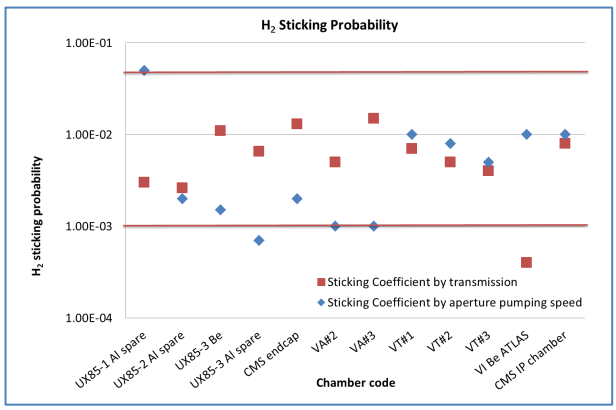


Figure 5: Measured $H_2$ sticking probability for different experimental chambers by transmission ratio and pumping speed of the beampipe entrance flange.

Figure 5 shows the hydrogen sticking probabilities calculated for several experimental chambers of different materials and geometry. In some cases the sticking probability calculated by the transmission factor s(T) do not overlaps with the one calculated by the pumping speed of the beampipe entrance flange s(Sa). In the two cases of s(Sa) higher than s(T) some of the contaminant gases produced during the injection might have not been taken into account since the entire RGA spectra of the injection is not available. In the cases where the s(Sa) is lower than s(T), the difference might be ascribed to an irregular bakeout and activation at the chamber extremities. The sensitivity of the transmission method to the presence of a saturated or not well performing zone along the chamber has not been studied for each specific chamber yet.

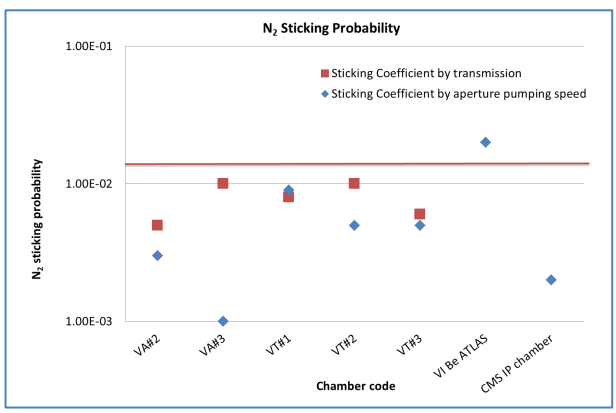


Figure 6: Measured $N_2$ sticking probability.

Figure 6 and Figure 7 show the nitrogen and carbon monoxide sticking probabilities obtained for some of the chambers tested. In all cases, the values obtained are lower than expected, probably due to the following reasons:

- During the injections, the RGA spectra showed a presence of hydrocarbons and noble gas that are not pumped by the NEG. Their amount varies from 50% to 100% of the gas arriving at the gauge $P_3$ and their presence reduces drastically the precision of the measurement.
- The amount of $CH_4$ at the extremity of the chamber was not counted in the overall gas contribution.
- For vacuum chambers with a length-over-radius ratio higher than 30 (which is the case of all experimental beampipes) and sticking probabilities higher than $5x10^{-2}$ (values expected for s(CO) and s($N_2$)) the transmission ratio does not depend on the sticking probability. This can be seen in Fig. 3: for sticking probabilities higher than $10^{-2}$ the transmission probability flatten and the values of sticking probability can be obtained only with a large error.

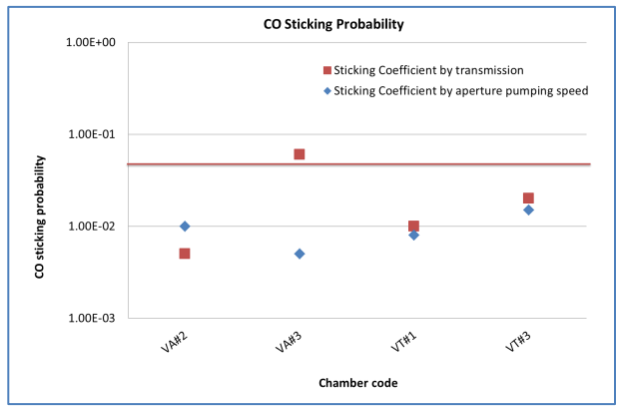


Figure 7: Measured CO sticking probability.

Considering the above observations, the chamber acceptance was finally based on the three more reliable parameters of the test: the pressure during the heating for NEG activation, the residual gas analysis, and the corrected hydrogen-sticking-probability measurement either by transmission or aperture pumping speed.

## ACKNOWLEDGEMENTS

Many thanks to all the technicians of the VSC group that helped prepare the experimental setup of each test.

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