SATURATION BEHAVIOUR OF THE LHC NEG COATED BEAM PIPES

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Abstract

In the CERN Large Hadron Collider (LHC), about 6 km of the UHV beam pipe are at room temperature and serve as experimental or utility insertions. TiZrV non-evaporable getter (NEG) coating is used to maintain the design pressure during beam operation.

Molecular desorption due to dynamic effects is stimulated during protons operation at high intensity. This phenomenon produces an important gas load from the vacuum chamber walls, which could lead to a partial or total saturation of the NEG coating. To keep the design vacuum performances and to schedule technical interventions for NEG reactivation, it is necessary to take into account all these aspects and to regularly evaluate the saturation level of the NEG coating. Experimental studies of a typical LHC vacuum sector were conducted in the laboratory in order to identify the best method to assess the saturation level of the beam pipe. Partial saturation of the NEG was performed and the effective pumping speed, transmission and capture probability are analysed.

INTRODUCTION

The LHC's storage ring is made of three different vacuum systems: 42 km of UHV beam vacuum at cryogenic temperatures, 48 km of insulation vacuum for the He distribution lines and the magnet cryostats and 6 km of UHV beam vacuum at room temperature, the latter serving as experimental and utility insertions and constituting the so-called Long Straight Sections (LSS).

The major part of the LSS beam pipes is made of 7 m long oxygen-free copper (OFC) chambers, with an internal diameter of 80 mm and a wall thickness of 2 mm. The vacuum chambers are connected by means of standard DN100 Conflat™ flanges. In order to ensure the required UHV conditions [1], these chambers are coated with a TiZrV NEG alloy, which is able to pump H_2, N_2, O_2, H_2O, CO and CO_2 after vacuum activation [2]. During beam operation at high energy, molecular desorption due to synchrotron radiation and electron cloud is stimulated, leading to a non-negligible degassing from the vacuum chamber's walls. The aim of this study is therefore to investigate the implications of this degassing and to determine the conditions indicating a partial or a total saturation of NEG vacuum chambers.

SATURATION ANALYSIS

In the framework of this study, the characterisation of the NEG saturation process was carried on following two different methods – one based on experimental measurements and one on computer simulations – whose results have been analysed and compared.

Transmission Method

The transmission method allows quantifying the performance of the NEG coating along the whole length of the chamber, thus leading to an accurate determination of its saturation level. It consists in measuring the pressure increase at both ends (entrance and end) of a NEG vacuum chamber while a given flow of a certain gas is being injected.

The ratio between the pressure values at the beginning and at the end of the coated vacuum chamber represents its transmission *Tr*:

$$Tr = \frac{\Delta P_{ENTRANCE}}{\Delta P_{END}}$$

where ΔP refers to the difference between the measured pressure and the initial one. Besides that, it is important to measure also the pumping speed – as it is seen by the vacuum gauges – and the capture probability of the vacuum chamber, which give other important information about its saturation level. Pumping speed S at the entrance of the NEG chamber is expressed in *[l/s]* and it is calculated as follows:

$$S = \frac{Q}{\Delta P_{ENTRANCE}}$$

where Q is the entering flow in *[mbar·l/s]*. Finally, the capture probability CP represents the probability for molecules to be absorbed after having entered the NEG chamber and it is calculated as:

$$CP = \frac{S}{S_{AP}}$$

S_{AP} is the ideal pumping speed of the aperture.

Monte Carlo Simulations

Monte Carlo simulations were also performed in order to evaluate the H_2 sticking factor of the NEG coating and to check if it is possible to find a matching between simulations' results and experimental data. The sticking factor s is defined as the probability for a particle to be permanently adsorbed by a wall per individual collision with it [3]. The chosen software for this purpose has been Molflow+, a C/C++ code which implements the test-particle Monte Carlo method, allowing the analysis under UHV conditions of complex geometries that can be created using a CAD program [4].

EXPERIMENTAL SETUP

The experimental setup is described in Fig. 1. It is a Fischer-Mommsen type dome with an internal conductance (*Ø=1 cm*); a *216 cm* long NEG-coated OFC chamber was connected to it.

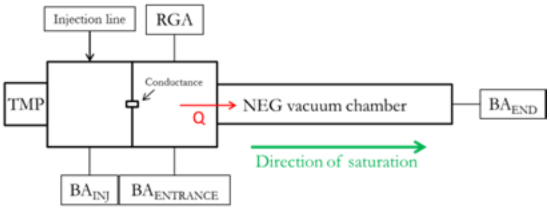

Figure 1: Schematic view of the experimental setup.

The dome was equipped with two hot cathode Bayard-Alpert gauges (BA) – respectively before and after the conductance – and with a RGA (Balzers QMG422 with a QMA 125 head); a third BA gauge was situated at the end of the NEG vacuum chamber. In addition to the pumping supplied by the coating, a turbomolecular pump (TMP) was installed on the dome, providing a nominal pumping speed of *60 l/s* for N_2.

Before starting measurements, a bake-out of the system was performed and the NEG coating was fully vacuum activated at *230 °C* for *24 h*.

EXPERIMENTAL RESULTS

The saturation of the NEG chamber was performed by means of several injections of CO; after every injection step, two small H_2 and N_2 injections were also performed. During the injections of gas, both TMP and RGA were constantly working. The aim of this operation was the measurement of the variations of transmission, pumping speed and capture probability for each gas as functions of the NEG saturation level.

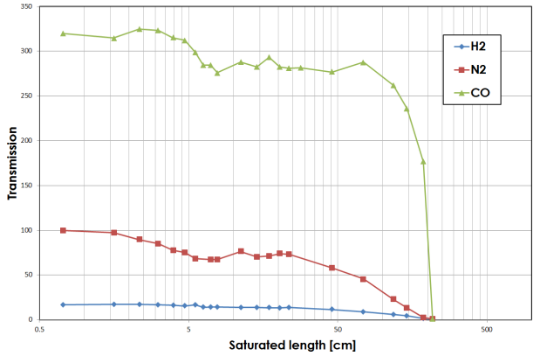

Figure 2: Transmission of H_2, N_2 and CO as functions of the NEG's length saturated by CO.

Table 1: Percentage of lost transmission for H_2, N_2 and CO at four different saturated lengths by CO

	Saturated length			
	17 cm	**75 cm**	**145 cm**	**188 cm**
H_2	80%	54%	26%	10%
N_2	90%	57%	17%	3%
CO	92%	90%	74%	55%

Figure 2 shows the transmission variations for H_2, N_2 and CO: as expected, transmission decreases for all gases as the saturated length increases, due to the fact that, if a larger NEG wall area is saturated, more gas molecules are able to reach the end of the vacuum chamber without being absorbed. When there is no more NEG surface activated, *Tr=1*, the pressure increase along the vacuum chamber is constant because there is no more pumping.

The percentage of lost transmission is shown in Tab. 1; CO transmission seems to decrease more slowly as saturation progresses, while for H_2 and N_2 it is reduced by approximately half of the initial value even if only one third of the total length is saturated.

The entrance pumping speed and capture probability decrease also following the same trend as CO saturation progresses. This behaviour could be explained by the different sticking coefficient of the NEG coating and the different adsorption mechanism for these gases. The sticking coefficient for CO, N_2 and H_2 is about *0.7*, *0.1* and $5{\cdot}10^{-3}$, respectively. The higher is the sticking coefficient, the higher is the transmission for different saturation lengths, as shown in figure 2. NEG coating adsorption mechanisms play an important role too.

The transmission curve for CO gives us important information about the saturation process of the NEG coating. The CO molecule needs one free site to be adsorbed. The saturation of the NEG vacuum chambers is progressive and due to the CO high sticking factor a small length of activated NEG is enough to keep the transmission to a constant value. However, this CO saturation front is responsible for the transmission decrease for H_2 and N_2: their pumping speeds are inhibited by the CO pre-adsorption. In particular for H_2 molecules, due to their low sticking coefficient, as the saturation front advances, a larger amount of gas molecules could reach the end of the NEG vacuum chamber. The NEG pumping mechanism for N_2 is different compared to CO and H_2: it requires to be adsorbed in many adjacent free sites underneath the first monolayer of the surface [5]. As the CO saturation front advances, beside the N_2 relatively high sticking coefficient, the number of active sites for the adsorption decreases and a major amount of gas could reach the end of the NEG vacuum chamber.

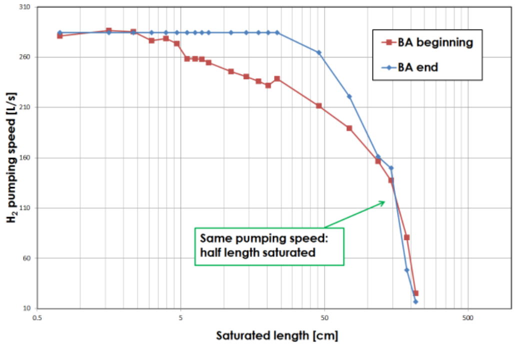

Figure 3: Pumping speed as a function of the saturated length for the BA beginning and BA end.

In Figure 3 is shown the pumping speed variation seen by the BA gauge at the end of the NEG vacuum chamber compared to the BA gauge located at its entrance. It is interesting to notice that the pumping speed seen by the BA located at the end remains constant after even more than 50 cm of NEG coated vacuum chamber results saturated. Both gauges are then characterised by the same pumping speed when the saturated length corresponds to half of the total chamber's length.

MOLFLOW+ SIMULATIONS

CAD models of the experimental setup were created in order to simulate the progressive saturation of the *2 m* long NEG chamber. This was made possible by applying a NEG sticking factor $s\neq 0$ on a gradually more and more limited pipe's wall area, assuming that NEG's saturation front progressively moves along the flow direction; a sticking $s=0$, representing the already saturated coating, was assigned to the more and more large wall area starting from the entrance of the chamber. H_2 injections were simulated assuming an incoming gas flow and transmission was plotted as a function of s for different saturated lengths, between $s=0.001$ and $s=0.01$ (Fig. 4).

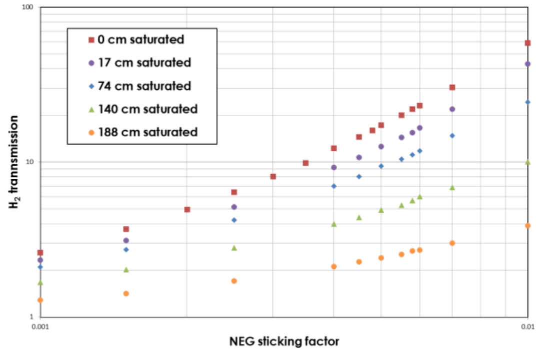

Figure 4: H_2 transmission as a function of the sticking factor for different saturated lengths.

As the saturated length increases, transmission for the same sticking factor decreases, showing the same behaviour observed for the experimental measurements.

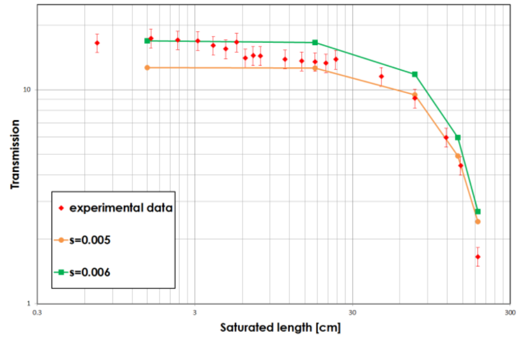

Figure 5: Measured and simulated H2 transmission as a function of the saturated length by CO for different s.

Furthermore, the experimental measurements of H_2 transmission as a function of the saturated length have been compared with the results of these latter simulations: an error of the *10%* was taken into account for the experimental data due to the uncertainty in pressure measurement of the BA gauges.

Figure 5 clearly shows that the simulated values perfectly match the experimental data if the NEG sticking factor for H_2 is comprised in the range between $5\cdot 10^{-3}$ and $6\cdot 10^{-3}$. These values are in very good agreement with the results of previous studies for a NEG surface with the same elemental composition [2].

APPLICATION TO THE LSS

Since 2009 pressure increases were measured in different areas of the LSS. Assuming that the thermal degassing in static vacuum conditions (no beam circulating) is constant, it is possible to determine the loss of pumping speed seen by the BA gauge in each vacuum sector.

Figure 6 shows a typical pressure distribution (obtained by VASCO code [6] simulations) in a vacuum sector where a pressure increase and consequently a loss of pumping speed due to collimator's outgassing were observed between 2009 and 2012.

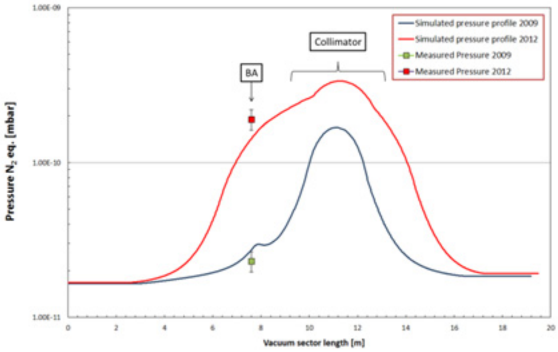

Figure 6: Example of pressure increase in a vacuum sector of the LSS.

This plot shows that the simulated pressure profiles are in good agreement with the pressure values measured by the BA gauges installed in the vacuum sectors of the LHC.

In summary, the work performed will permit to evaluate the evolution of pressure inside the LSS NEG coated vacuum chambers and to estimate their saturated length, allowing to foreseen future interventions in the LHC accelerator.

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ISBN 978-3-95450-115-1