THE VACUUM STUDIES FOR LHC BEAM SCREEN WITH CARBON FIBER CRYOSORBER

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Abstract

The beam vacuum chamber inside some cryogenic elements in the Long Straight Sections (LSS) of the Large Hadron Collider (LHC) in CERN (Geneva, Switzerland) will have cold bore temperature of 4.5 K and a beam screen (BS) at temperature between 5 and 20 K. The gas molecules desorbed due to photons, electrons and ions will pass through the slots on the beam screen to the shadowed part between the cold bore and the beam screen. All desorbed gases except for H_2 could be re-adsorbed on the cold bore and beam screen but a cryosorber is required to pump H_2. The measurements of basic vacuum properties of LHC beam vacuum chamber prototype with different cryosorbers are performed at the Budker Institute of Nuclear Physics (BINP) within the framework of collaboration BINP-CERN. The previous cryosorption studies were carried out with charcoal and nonwoven carbon fiber cryosorber. The present work includes a study with woven carbon fiber cryosorber. The main result of this work is that the woven carbon fiber cryosorber can be proposed for application in the LHC LSS vacuum chamber.

INTRODUCTION

In the present design of the LHC the majority of vacuum chamber will be at cryogenic temperatures. The so-called beam screen, maintained at temperature between 5 and 20 K by gaseous helium flow, will be inserted inside the cold bore, the vacuum envelope, to protect them against the synchrotron radiation, electrons and ions exposure [1].

About 2 × 24 km of LHC vacuum chamber walls in the arcs will be at 1.9 K, the temperature of superconducting magnets, and desorbed molecules will be pumped through the slots in the beam screen onto the cold bore. However, about 2 × 500 m of the LHC Long Straight Sections will be operated at 4.5 K. In this case, the H_2 adsorption capacity of cold bore is quite low (~10^{15} molecule/cm^2) and the use of the special cryosorbing material mounted on the shadowed (i.e. outer) side of the beam screen is required. The cryosorbing material should have the required adsorption capacity and pumping speed for H_2 in the range of temperatures between 5 and 20 K, the operating temperatures of the beam screen, in the real LHC LSS beam pipe configuration [1, 7]

The measurements of basic vacuum properties of LHC beam vacuum chamber prototype with different cryosorbers are performed at the Budker Institute of Nuclear Physics within the framework of collaboration BINP-CERN. The experimental studies of the different cryosorbing materials at 4.5 K performed at CERN [2] and BINP show that the capacities of certain metallic foams, filters, anodized Al and some other materials are low for LHC. Thus, the previous cryosorption studies were carried out for beam screen with charcoal [4, 6] and nonwoven carbon fiber fabric [5]. Results of studies show that the capacities of both the charcoal and nonwoven carbon fiber are enough for vacuum chamber inside the LHC LSS at the beam screen temperatures lower than 25 K. However, charcoal crumb fixation onto the beam screen is a complicated procedure and, in principle, charcoal crumb can be a source of micro-particle dust in the beam vacuum chamber. The fluffs can come off the nonwoven carbon fiber cryosorber. The main sources of the fluffs are the material cut edges. So, a search for non-dust cryosorbers with large adsorption capacity is continued.

One of such cryosorbers can be a woven carbon fiber material with specially treated edges. The present work includes a study with woven carbon fiber cryosorber. The results show that 100÷200 cm^2 of woven carbon fiber has sorption capacity more than 10^{20} *molecules* at temperature lower than 29K and equilibrium hydrogen density less than 10^{15} $molecule \cdot m^{-3}$, that meet the LHC requirements. The woven carbon fiber material has an additional advantage because this material is not crumbled and provides a convenient fixation onto BS comparing to charcoal. Thus, woven carbon fiber cryosorber can be proposed for application in the LHC LSS vacuum chamber.

EXPERIMENTAL SETUP AND METHOD

The special experimental stand at BINP was modernized to study the vacuum parameters of a prototype of the LHC vacuum chambers with a woven carbon fiber cryosorber. The layout of experimental setup and experimental method was described in detail in refs. [4, 5, 6].

A 1-m long LHC vacuum chamber prototype consists of a 50-mm ID cold bore with a beam screen inside. The cross-section of the studied LHC beam pipe prototype with carbon fiber material is shown in Fig. 1. Since the cold bore in the experimental stand is a part of the cryostat, therefore it is at the temperature of either liquid helium (LHe) or nitrogen (LN_2) filling the cryostat.

The beam screen was made at CERN with the parameters given in the Table 1. The beam screen thickness is 0.65 mm. There are 8 rows of pumping slots on the LHC beam screen. The average length of a slot is 8 mm. The average distance between the slots is 8 mm. The slot width is 0.9 mm. The total area of slots is 2.4% of the inner beam screen surface. The beam screen is cooled by adjustable flux of cold gaseous helium flowing via the cooling pipes welded to the beam screen. The beam screen temperature is measured with a thermometer fixed on the beam screen.

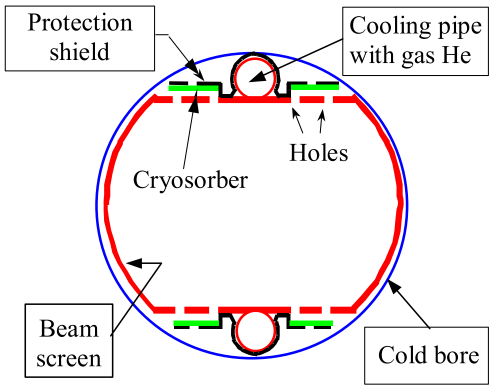

Figure 1: Cross-section of the studied LHC beam pipe prototype with woven carbon fiber cryosorber.

Table 1: The beam screen parameters.

Parameter	R (radial), [mm]	V (vertical), [mm]
Inner Diameter	47.2	37.6
Wall Thickness	0.65	0.65
Outer Dimension	48.5	38.9

Four 5-mm wide strips of carbon fiber cryosorber were glued onto the special protection shields made in CERN. Protection shield is fixed onto the outer part of the beam screen along the cooling pipes. The total geometrical cryosorbing area of the carbon fiber is about 200 cm^2.

The pressure in the vacuum chamber is measured simultaneously by the Bayard-Alpert ion gauge and the PMM-46 inverted magnetron gauge, placed in the warm part of vacuum chamber.

An adjustable hydrogen flux was injected into the test vacuum chamber to study the vacuum properties of LHC vacuum chamber prototype with carbon fiber cryosorber. The special gas-distribution pipe was placed inside the test chamber to simulate the uniform gas desorbtion along the LHC vacuum chamber prototype. It was made of 1-m long and 12.4-mm ID stainless steel tube with ten 0.5-mm ID holes along it for the quite uniform H_2 injection. A copper strip was brazed to the outside of this injection pipe to ensure a uniform temperature along it. The end of the tube was welded closed.

In the beginning of the experiment, the valve at entrance of injection line was closed. Then the valve was opened and H_2 injecting into the test chamber commenced. The pressure at entrance of injection channel was kept constant, the pressure in the room temperature part of the test chamber and a number of adsorbed molecules were measured as a function of time for a continuous gas flux into the test chamber. The gas flux Q [$Pa{\cdot}m^3/s$] is defined at the known injection channel conductance U_c=$3{\cdot}10^{-6}$ [m^3/s] by the measured pressure P_1 [Pa] at the entrance of injection line and the pressure in the vacuum chamber P [Pa]. Since pressure in the test chamber was much lower than that at the injection line entrance during the whole time of the experiment, then the gas flux is:

$$Q = P_1 U_c \quad (1)$$

therefore the beam screen pumping speed S [m^3/s] at beam screen temperature T_{BS} [K] can be defined during gas injection as:

$$S = \frac{P_1 U_c}{\Delta P}\sqrt{\frac{T_{BS}}{T_{RT}}} \quad (2)$$

where the dynamic pressure in the test chamber $\Delta P = P - P_{bg}$ is defined as the difference between the current measured pressure P and the background pressure P_{bg}, measured without gas injection in the beginning of the experiment. The pressures were measured at room temperature T_{RT} [K]. Thus, the beam screen pumping speed can be evaluated from the two pressures, P and P_1, measured at permanent gas flux injected into the vacuum chamber.

The gas density inside BS n [$molecules/m^3$] at BS temperature T_{BS} [K] can be calculated as:

$$n = \frac{\Delta P}{k_B \sqrt{T_{BS} T_{RT}}} \quad (3)$$

where k_B is Boltzmann constant.

The value of the gas density limit in LHC beam channel (10^{15} $molecules/m^3$) was used for defining of the adsorption capacity of LHC LSS vacuum chamber prototype with carbon fiber in the experimental measurements of isosteres at different numbers of adsorbed molecules.

EXPERIMENTAL RESULTS AND DISCUSSION

The measurements of isosteres at different numbers of adsorbed molecules and determination of the cryosorbtion capacity of the LHC LSS vacuum chamber prototype with woven carbon fiber were carried out at cold bore temperature T_{CB}=4.3 K.

The accumulated dose of $1.1{\cdot}10^{20}$ molecules was obtained by hydrogen injection during about 1 hour. Gas flux was $3{\cdot}10^{16}$ molecule/sec. Then gas flux was interrupted to reach an equilibrium state.

The isostere was measured with decreasing BS temperature step by step. The waiting time of the equilibrium pressure for each point was about 30 minutes. The measured gas density n inside the LHC vacuum chamber prototype at different numbers of adsorbed molecules versus the beam screen temperature T_{BS} is shown in Fig. 2.

One can see that 100÷200 cm^2 of woven carbon fiber has sorption capacity more than 10^{20} *molecules* at temperature lower than 29K and equilibrium hydrogen density less than 10^{15} $molecule{\cdot}m^{-3}$, that meet the LHC requirements.

After these measurements the injection with the higher H_2 flux Q=10^{17} molecule/s was used to reach the larger number of adsorbed molecules. The measured isostere at the dose $1.1 \cdot 10^{21}$ molecules shows that gas density level acceptable for LHC is only obtained at beam screen temperature lower than 15 K. However, we suppose that the necessary time to reach an equilibrium pressure was not enough.

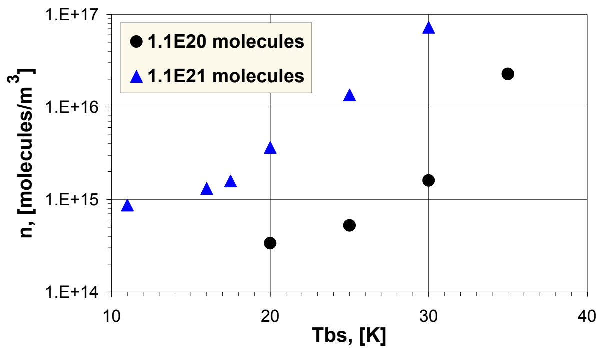

Figure 2: Isosteres at different numbers of adsorbed molecules. Cold bore temperature T_{CB}=4.3 K.

The direct measurement of the adsorption isotherm as a function of the number of adsorbed molecules is also difficult in practice since, after the gas flux interruption, the vacuum system returns to the equilibrium state (i.e. without gas injection) only after a very long time [8].

The pumping speeds of the BS with woven carbon fiber were experimentally measured of as a function of the total number of adsorbed molecules during gas injection in different experiments at the BS temperatures 20, 21 and 25 K.

The pumping speeds obtained for different beam screen temperatures Tbs at total injected gas flux $Q=10^{15}$ molecules/sec are shown in Table 2. However, the pumping speed reduces slowly with an increase in the total number of adsorbed molecules. This fact can be explained by the slow diffusion of the adsorbed gas inside the cryosorber at cryogenic temperatures and by the gradually decrease in the free part of cryosorber surface. Thus, the pumping speeds in Table 3 are given for several typical amounts of adsorbed gas N, namely 10^{19}, 10^{20} and 10^{21} molecules.

Table 2: Pumping speeds of beam screen with woven carbon fiber cryosorber.

T_{BS}, [K]	Pumping speed [m^3/sec] for H_2 at 10 K.		
	at dose 10^{19} molecule/m	at dose 10^{20} molecule/m	at dose 10^{21} molecule/m
20	0.166	0.116	0.081
21	0.153	0.116	0.062
25	0.142	0.087	0.050

The obtained results characterize the pumping speed of beam screen with carbon fiber at T_{BS} near the top of the BS operating temperature.

The adsorption measurements were repeated after a short time of cryosorber regeneration at low temperatures. The experimental result is that the carbon fiber cryosorber can be operated after regeneration at ~80K less than 1 hour. The total quantities of adsorbed molecules after regenerations were measured to be no less than $5 \cdot 10^{20}$ molecules for beam screen at T_{BS}=18 K.

CONCLUSION

A woven carbon fiber material was proposed to cryosorb hydrogen in the LHC LSS cryogenic vacuum chambers. The isosteres at different numbers of adsorbed molecules and pumping speeds of beam screen with woven carbon fiber at different BS temperatures were measured for the LHC LSS vacuum chamber prototype. This carbon fiber material has shown the sufficient sorption capacity for hydrogen at operational temperatures of the beam screen in the LHC LSS. It is also very important that this material is not crumbled and provides a convenient fixation onto BS comparing to charcoal.

The results of these studies show that carbon fiber material is interesting as cryosorber-candidate for use in the LHC and other long vacuum system at cryogenic temperatures.

ACKNOWLEDGMENTS

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