GAS CONDENSATES ONTO A LHC TYPE CRYOGENIC VACUUM SYSTEM SUBJECTED TO ELECTRON CLOUD

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Abstract

In the Large Hadron Collider (LHC), the gas desorbed via photon stimulated molecular desorption or electron stimulated molecular desorption will be physisorbed onto the beam screen held between 5 and 20 K. Studies of the effects of the electron cloud onto a LHC type cryogenic vacuum chamber have been done with the cold bore experiment (COLDEX) installed in the CERN Super Proton Synchrotron (SPS). Experiments performed with gas condensates such as H_2, H_2O, CO and CO_2 are described. Implications for the LHC design and operation are discussed.

INTRODUCTION

The Large Hadron Collider (LHC), under construction at CERN, is designed to collide ions and protons beams at high luminosity. The proton-proton collisions at 7 TeV require the use of large magnetic fields obtained using superconducting technology. In the arcs and in some elements of the long straight section (LSS), the cold bores (CB) at 1.9 K or 4.5 K will be protected from the heat dissipated by the beams by the beam screen (BS) held at 5 to 20 K. The pumping towards the CB is ensured by slots located on the BS. The BS transparency is 4 %. The circulation of the bunches (1.1 10^{11} protons/bunch) spaced by 25 ns will provoke the build up of an electron cloud. This electron cloud will interact with the proton beam, causing emittance growth, particle losses and will interact with the BS, provoking molecular desorption and dissipating heat load onto the BS. The vacuum chamber geometry, its surface properties (electron reflectivity, secondary electron and photoelectron yields) and the beam characteristics (filling pattern, bunch current, bunch spacing) are the most important parameters which drive the electron cloud. Since the LHC operates at cryogenic temperature, it is important to understand the behaviour of the vacuum system in presence of condensed gas onto the BS. The cold bore experiment (COLDEX), installed by 2002 in the CERN Super Proton Synchrotron (SPS), has been used to this goal.

EXPERIMENTAL SET UP

COLDEX is installed in a by-pass of the SPS. Before an experiment the system is moved into the beam path and the valves located at each extremity are opened. The total length of the experiment is 5 m. At each extremity of COLDEX is installed a 0.3 m long cold warm transition (CWT) which acts as a trap against the gas desorbed in the room temperature (RT) vacuum chambers. COLDEX is made of a 2.2 m long copper BS inserted into a stainless steel CB. The BS transparency is 1 %. The total and partial pressures are measured in the centre and extremities of COLDEX. A dedicated cryoplant provides the liquid He to the experiment. The temperature of the BS is controlled from 5 to 200 K by gaseous He. The CB is controlled at 3 K by a liquid He bath. The heat load dissipated onto the BS is computed from the measure of the increase of the He temperature and the mass flow along the BS. In 2002, the BS was perforated with holes. It has an elliptical shape with 84 mm horizontal axis and 66 mm vertical axis [1]. In 2003, the BS was perforated with slots and the protection of the CB against heat load was increased by the addition of electron shields located behind the slots. The BS was circular with 67 mm inner diameter [2]. Before an experiment, the whole system, with the exception of the BS, the CB, the CWT and the central port, was baked to 300°C for 24 h. The SPS is an unbaked machine.

During the experiments, the SPS is partly filled with the LHC type proton beams. They are made of 1 to 4 batches. Each batch is separated by 225 ns. A batch is made of 72 proton bunches (1.1 10^{11} protons/bunch), separated by 25 ns. The SPS filling factor varies from 8 to 32 % as opposed to the LHC which will be filled to 79 %.

RESULTS

Effect of Condensed Gases

Despite a cleaning of the vacuum chambers according to UHV standard, it is known that the first circulation of a beam stimulates molecular desorption via photon or electron bombardment on the vacuum chamber. The consequence of this phenomenon is illustrated by the first experiment performed in 2002.

Figure 1 shows the evolution of the heat load onto the BS when 2 batches circulated through COLDEX. From 0 to 100 h, the heat load increased up to 6 W/m while the BS and CB operate at 20 K. In the same time, the total pressure measured in the centre of COLDEX decreased from 10^{-6} Torr to 5 10^{-8} Torr. The accumulated electron dose is estimated to be 3 10^{19} e/mm^2.

At 80 h, the cooling of the BS was stopped and the BS warmed up to ~ 40 K during which H_2, CH_4 and CO were removed from the BS. After cooling back to the initial temperature, the dissipated power remained the same. Thus, none of these gases is the origin of the heat load.

At 100 h, the beam was switched off and the BS and the CB temperature were increased to 240 K and 120 K respectively. As expected, the desorption of condensed gas was noticed, mainly H_2O and CO_2. Indeed, the proton beam circulating in the unbaked part of the SPS by-pass and / or the CWT with the BS produced a strong desorption during which a few tens of monolayers were desorbed. While the BS and CB were at 240 K and 120 K the beam was circulated for 4 h.

At 150 h, the BS and CB were cooled down to 10 K and 4.2 respectively. The heat load dissipated onto the BS, now having a bare surface, decreased to 1 W/m. Due to a reduced gas load, the dynamic pressure was less than 5 10^{-8} Torr, the growing of the condensed layer onto the BS was much less than initially, the dissipated heat load remains at 1 W/m up to an accumulated dose of 20 A.h. Any subsequent warm up of COLDEX to RT did not change the amount of the dissipated heat load onto the BS at cryogenic temperature.

So, the origin of the initial increase of the dissipated heat onto the BS is attributed to the presence of condensed gas (either H_2O or CO_2). Indeed, the condensation of H_2O is known to increase the maximum of the secondary electron yield [3]. Since H_2O is significantly desorbed in unbaked vacuum chambers, it is a good candidate for the origin of the initial increase of the dissipated heat onto the BS.

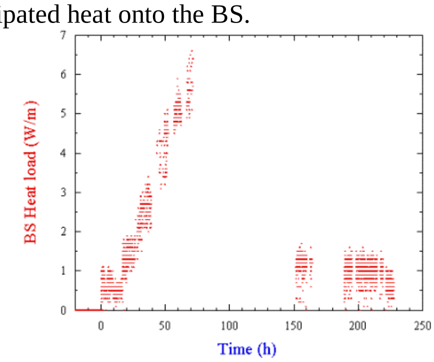

Figure 1: Heat load due to condensed gases onto the BS when 2 batches circulated through COLDEX.

During the experiment performed in 2003, since most of the gas was previously released from the vacuum chambers, no increase of the heat load was noticed due to the condensed gas after 12 A.h. A conditioning of the system was observed [2]. Again, any subsequent warm up to RT before cool down did not change significantly the amount of dissipated heat onto the BS.

Atmospheric Gases and Thermal Desorption

During the LHC operation, the vacuum system will be exposed to thermal desorption or to atmospheric gas after a venting. No significant differences in the pressure and the heat load as compared to Figure 1 after 220 h were observed in the following dedicated experiments : 1) COLDEX was held at RT for 2 months under vacuum at 10^{-8} Torr before cool down, 2) COLDEX was vented, pumped down to 10^{-8} Torr and cooled down, 3) COLDEX was exposed to atmospheric pressure for 2 weeks; pumped down to 10^{-4} Torr and cooled down.

So, the conditioning of the LHC vacuum system will not be altered during the shutdown or after a venting.

Injections of Gas

In the case of an excessive surface coverage onto the BS after a quench or after the dissipation on the BS of a larger heat load, a vacuum transient appears [4]. To simulate the behaviour of the BS in the presence of condensed gas, injections of gas were performed. With the valves closed, the CB held at 200 K and the BS held at 5 K, the gas is admitted into the system at one extremity. After injection, a special procedure is applied to obtain a uniform surface coverage onto the BS while cooling down to 5 K. Finally, the CB is cooled down to 3 K.

Figure 2 shows the results of the condensation of 10^{15} H_2/cm^2 onto the elliptical BS. As observed under synchrotron radiation bombardment, a pressure rise is seen. This rise, up to 6 10^{-8} Torr, is due to the H_2 recycling into the gas phase. The observed decay within a few hundredths of A.h is due to the flushing of the gas towards the CB. The recycling desorption yield, η', is computed from the ratio of the pressure increase to the pumping speed time the electron flux. For a sticking probability, σ, of 1, it equals 3 H_2/e^-. In the meantime, no increase of the heat load with respect to a bare surface after 20 A.h beam conditioning was noticed.

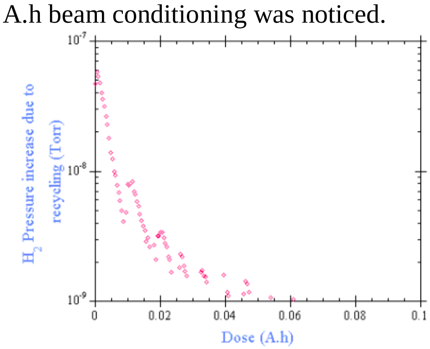

Figure 2: H_2 dynamic recycling pressure when 2 batches circulated with10^{15} H_2/cm^2 condensed onto the BS

Figure 3 shows the dynamic pressure due to the recycling desorption observed when 1 batch circulated through COLDEX after the condensation of 5 10^{15} CO/cm^2 onto the circular BS. The pressure increased to 10^{-8} Torr, however due a lower η' than H_2, the flushing of CO towards the CB was less effective. The pressure remains 5 times larger than the 100 h life time limit for at least 0.5 A.h. For σ ~ 1, η' equals 0.4 CO/e^-. Similarly to the H_2 case, no increase of the heat load larger than 0.1 W/m was noticed as compared to a bare surface after 12 A.h conditioning.

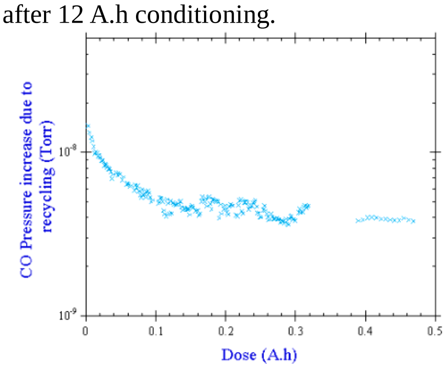

Figure 3: CO dynamic recycling pressure when 1 batch circulated with 5 10^{15} CO/cm^2 condensed onto the BS.

Thick layers of CO condensed onto the BS have dramatic effects. Figure 4 shows heat load up to 6 W/m (when 1 batch circulated up to 1 A.h and 4 batches afterwards) after the condensation of 60 10^{15} CO/cm^2.

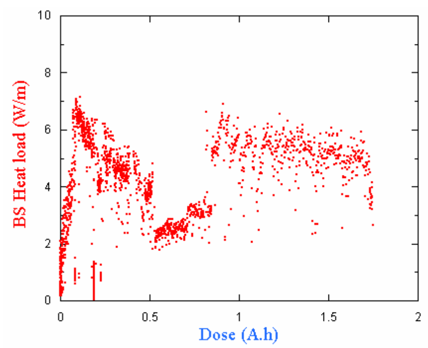

Figure 4: BS heat load when 1 to 4 batches circulated with 60 10^{15} CO/cm^2 condensed onto the BS.

The condensation of 15 10^{15} CO_2/cm^2 onto the circular BS showed a similar behaviour to the one reported in the CO case with 5 10^{15} CO/cm^2. However, most of the CO_2 molecules cracked into CO and O_2. Thus, the residual gas analysis was dominated by CO. The ratio between the CO_2 to CO partial pressures is 1/7. For $\sigma \sim 1$, η' equals 0.01 CO_2/e^-. Due to the low η', when 4 batches were circulated, after a dose of 1 A.h, the pressure remains 15 times larger than the 100 h life time limit. Again, no increase of the heat load larger than 0.1 W/m was seen as compared to a bare surface after 12 A.h conditioning.

IMPLICATIONS FOR THE LHC

The condensation of gas onto the cryogenic vacuum system could hamper the operation of the LHC. In all cases, the amount of gas condensed onto the BS should be controlled. During the cool down, the temperature of the BS will remain above the CB temperature in order to condense all the gases onto the CB. Before a venting of the vacuum system, it should be ensured that the whole sector is at about RT to avoid the condensation of gases. During shutdown, the LHC will be warmed up to 240 K while the released gas will be evacuated by turbomolecular pumps. Generally, the surfaces with large gas load and located close to the BS, should be minimised to avoid the growing of thick condensed layers of gas. For instance, the CWT might be baked to reduce the stimulated desorption. Since the cold vacuum system is a closed geometry, any desorbed gas will remain condensed onto the BS and the CB, thus a BS heater is required to control the BS surface coverage. For example, in the case of a magnet quench, an accumulation of the gas onto the BS is possible [4]. Figure 5 shows the computed vacuum transients due to the electron cloud after the condensation over 2 m onto the BS of 25 10^{15} CO/cm^2. Despite that the machine operates within the cryogenic budget, 1.5 W/m, a CO pressure increase will quench the closest magnet(s). A lower beam current (0.1 W/m during a day) reduces the risk of a quench but, due to the nuclear scattering, still dissipates 1 W/m/beam to the neighbour cold masses. So, after a quench, the BS will be warmed up to flush the gas towards the CB. In the LSS, a systematic decoupling of the RT and cryogenic vacuum systems is done by the vacuum valves. It protects the getter coated vacuum chambers while warming up the BS.

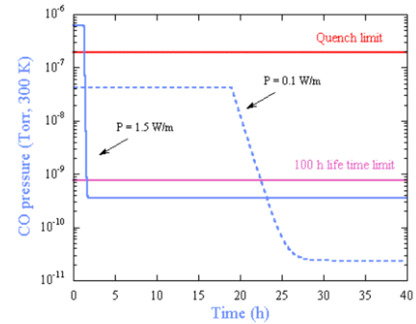

Figure 5: Vacuum transients computed after a quench and the condensation of 25 10^{15} CO/cm^2 onto the BS.

CONCLUSIONS

The presence of the electron cloud in the LHC requires a deep understanding of the behaviour of the vacuum system. Studies performed in a LHC type cryogenic vacuum system subjected to the electron cloud have been done. The consequences of the gas condensation onto the BS have been analysed. Heat load and / or pressure rises are observed. The recycling yields of usual molecules, to be used for the vacuum calculations, were measured. The condensation of thick layers of gas such as H_2O and CO induced large heat loads. To optimise the vacuum system operation, the amount of condensed gas onto the BS shall be controlled. It has been shown that, in some cases, the recycling pressure of the condensed gas could be larger than the 100 h life time limit. The vacuum transients, which might be observed after a magnet quench, have been simulated experimentally and computed. Such transients are undesirable since they might produce a quench, activate the accelerator components and dissipate significant heat load into the cold masses. To recover the life time or avoid the vacuum transients, the flushing of the condensed gas onto the BS towards the CB will be done during dedicated periods. Such a flushing is done with BS heaters. In the neighbourhood of the LSS, the vacuum valves will be closed to protect the getter coated vacuum chambers during warming up the BS. However, while quenching, some gas could be desorbed towards the RT vacuum chambers altering their performances.

ACKNOWLEDGEMENTS

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