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FIRST RESULTS FROM COLDEX APPLICABLE TO THE LHC CRYOGENIC VACUUM SYSTEM

V. Baglin, I.R. Collins, C. Grünhagel, O. Gröbner and B. Jenninger

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A cold bore experiment (COLDEX) has been installed in the electron-positron accumulator (EPA) at CERN. The ~2 m long COLDEX cryostat, that may be cooled to below 3 K, is fitted with an actively cooled perforated beam screen to simulate the conditions in the cold arcs of the LHC. Initially, gas desorption yields were obtained using an external synchrotron radiation beam line by exposing the beam screen to grazing incident radiation with a critical energy of 194 eV.

In an extended period of EPA operation and during a dedicated period for LHC studies, COLDEX was installed into the EPA ring to study more specifically the influence of the bunched positron and electron beams with the cold bore / beam screen vacuum system.

The results from these experiments and some predictions applicable for the LHC will be presented.

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A cold bore experiment (COLDEX) has been installed in the electron-positron accumulator (EPA) at CERN. The ~2 m long COLDEX cryostat, that may be cooled to below 3 K, is fitted with an actively cooled perforated beam screen to simulate the conditions in the cold arcs of the LHC. Initially, gas desorption yields were obtained using an external synchrotron radiation beam line by exposing the beam screen to grazing incident radiation with a critical energy of 194 eV.

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1 INTRODUCTION

The proton beam of the Large Hadron Collider (LHC) will emit, inside the 8 T superconducting bending magnet, an intense synchrotron radiation (SR) with a critical energy of 45 eV. The 10^{17} photons/m/s will induced molecular desorption from the beam screen designed to protect the 1.9 K cold bore from heat loads induced by the beam. The primary photodesorbed gas species (H_2, CH_4, CO and CO_2) will be re-adsorbed onto the 5-20 K beam screen causing either a recycling photodesorption of these gas species and/or an increase of the H_2 vapour pressure. These pressure increases will be limited by the slots along the beam screen by allowing the desorbed gas to be condensed onto the cold bore.

In order to assure a beam lifetime of 100 h, the parameters *i.e.* primary η and recycling η' photodesorption yields, sticking coefficient σ and vapour pressure, describing the above phenomena must remain within fixed bounds. For this purpose a number of experiments have been undertaken and particularly, a cold bore experiment (COLDEX) has been set up and installed in the ~ 126 m circuference electron-positron accumulator (EPA [1]) at CERN.

2 EXPERIMENTAL DETAILS

2.1 COLDEX instrument

The ~ 2 m long COLDEX instrument, built in collaboration with Nikhef [2], is made of two concentric chambers, the inner one being a demountable liner and the outer one being a double walled vessel called cold bore. The liner, which simulates a LHC type beam screen, is made of solid OFE Cu and can be temperature controlled from 5 to 100 K. The stainless steel cold bore can be temperature controlled from 2.5 to 4.2 K (below 3 K, the saturated vapor pressure of H_2 is vanishingly small). The chambers had been cleaned following standard UHV procedures. The partial pressures inside the liner are measured at room temperature by a calibrated residual gas analyser (RGA 3, see Fig. 1). A chimney separated by ~ 1 mm from the liner, allows the molecules to escape from the inner part of the liner towards RGA 3 by minimising parasitic physisorption.

2.2 Experimental systems

The COLDEX instrument was installed on an existing beam line of EPA [3] designed to measure the photodesorption yields of materials such as Al, Cu and stainless steel. Fig. 1. shows a schematic of COLDEX on the beam line. The SR emitted inside the dipole field by the 500 MeV electrons is collimated and irradiates the COLDEX inner walls (ID 47 mm) at a mean incidence angle of 11 mrad. For the beam line experiments, the produced SR spectrum has a critical energy of 194 eV and an intensity of 3.4 10^{16} photons/m/s. The collimation attenuates the SR spectrum for photons with an energy below 4 eV.

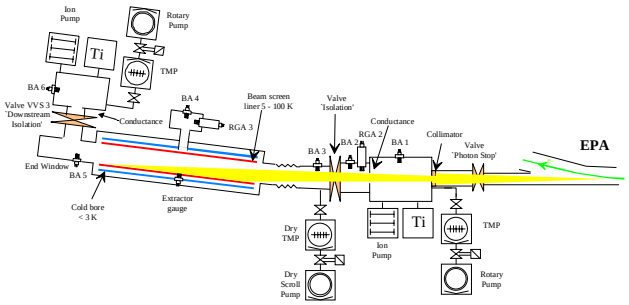

Figure 1: Layout of the COLDEX installed in the EPA photon beam line.

In a second phase, the COLDEX instrument was installed into the EPA ring, at one end of a long straight section, in order to study the influence of the electron and positron beams with a cryogenic vacuum system. Fig. 2. shows a schematic of the COLDEX installed inside the EPA ring. With an electron beam, the COLDEX inner walls (ID 67 mm) were irradiated by SR produced inside the dipole magnet BHZ 58 with an intensity of ~ 8 10^{16} photons/m/s. On the other hand, with the counter rotating positron beam no SR was incident on the system and thus only the influence of the beam with the instrument could be observed. Electron /

positron beams of 500 MeV energy and 1 to 8 bunches with respectively 8 10^{10} and 5 10^{10} particles/bunch traversed COLDEX.

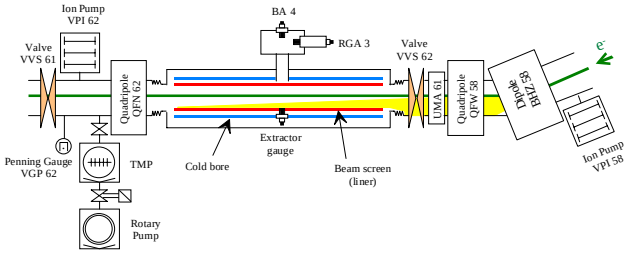

Figure 2: Layout of COLDEX installed inside the EPA ring exposed to SR from circulating electrons.

3 RESULTS ON THE BEAM LINE

3.1 Long term irradiations

The COLDEX cold bore was first cooled to 3.5 K and then the perforated liner was cooled from 130 K down to 19 K. In doing so, the initial surface gas coverage on the liner was minimised. Fig. 3. shows the evolution of the partial pressures observed at RGA 3. H_2 was the dominant gas species desorbed followed by CO and CO_2. Being in a quasi-closed geometry, the photodesorbed hydrogen could be physisorbed onto the internal surface of the perforated liner where it could be in turn 'recycled' into the gas phase by the photons. This is illustrated by the hydrogen pressure increase observed during the exposure to about 5 10^{20} photons/m. At equilibrium, the amount of H_2 desorbed by recycling is exactly balanced by the amount of gas pumped onto the inner surface of the perforated liner *i.e.* the surface coverage ceases to increase. As a result of a vanishing net pumping of the liner, the H_2 photodesorbed from the surface is pumped directly via the ~ 1 % holes on the cold bore. This is illustrated by a constant partial pressure observed up to an accumulated dose of ~ 5 10^{21} photons/m. The irradiation was then stopped, it was checked that the H_2 vapour pressure was negligeable and the liner temperature was temporarly raised to 52 K. During this warm up, the hydrogen accumulated onto the liner was completely desorbed. After having cooled the liner to 11 K and the cold bore to 3.5 K, the irradiation

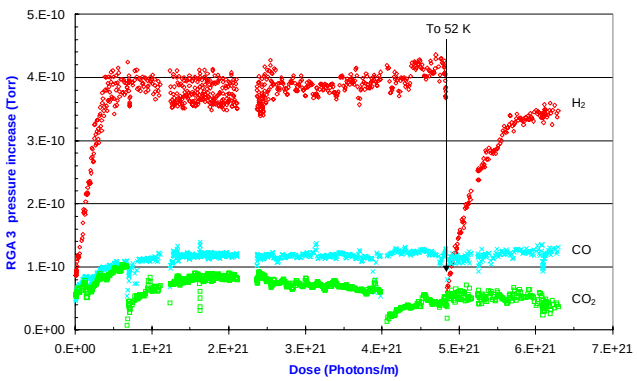

Figure 3: Photon induced gas desorption of a perforated liner held at cryogenic temperature.

was restarted. As expected, the H_2 pressure increases again and saturates at a similar level as shown. Further experiments, reproducing the above irradiation with different liner temperatures indicate that the H_2 primary photodesorption yield is constant in the range from 5 to 20 K.

The behaviour of the other gases can be interpreted in a similar way, however, since their respective recycling yields are much lower than that of H_2 the effect is thus less visible [4].

3.2 Temperature dependence

After having irradiated the liner with 3 10^{22} photons/m in order to reduce any significant further cleaning during the experimental session, the temperature of the perforated liner was decreased in steps from 100 K to 5 K whilst the cold bore was held at 2.9 K. Table 1 shows a selection of the measured primary photodesorption yields. All the yields, with the exception of H_2, were measured at a temperature at which the studied gas was not physisorbed to any significant amount onto the liner. As demonstrated in 3.1 and shown in Fig. 3., the H_2 primary photodesorption yield could be measured down to 5 K due to the equilibrium provided by the pumping through the liner holes. In Table 1, it can be seen that the primary photodesorption yields decrease for decreasing temperature. From the respective gas loads, the sticking probability of the molecules on an OFE Cu 'bare surface' subjected to irradiation is found to be of the order of a few percent.

Table 1: Primary photodesorption yields at selected temperatures for OFE Cu subjected to SR with 194 eV critical energy.

T (K)	H_2	CH_4	CO	CO_2
5	2 10^{-4}	-	-	-
78	4 10^{-4}	6 10^{-6}	2 10^{-5}	-
114	7 10^{-4}	2 10^{-5}	1 10^{-4}	4 10^{-5}
300	8 10^{-4}	2 10^{-5}	3 10^{-4}	2 10^{-4}

3.2 Recycling of hydrogen

To further demonstrate the strong H_2 recycling yield shown in Fig. 3., H_2 was injected inside the COLDEX UHV system prior to the irradiation. For this purpose, the valves isolating COLDEX from external pumping were closed and the H_2 gas was injected when the perforated liner was at 5 K and the cold bore at ~ 180 K. The temperature of the liner was then raised gently to ~ 12 K where, due to the high vapour pressure, the gas could be evently distributed onto the liner. Finally, the liner was cooled to 5 K and the irradiation was started. Fig. 4. shows the H_2 transient pressure increase induced by the photons for a pre-condensed surface coverage of 1.6 10^{15} and 3.2 10^{15} H_2/cm^2. One observes the recycling photodesorption phenomenon followed by a pressure reduction which can be attributed to the escape of the desorbed gas towards the extremities of COLDEX. As depicted, for such an initial surface coverage, the

pressure increase is 2 orders of magnitude larger than in the case of a 'bare surface' (Fig. 3.).

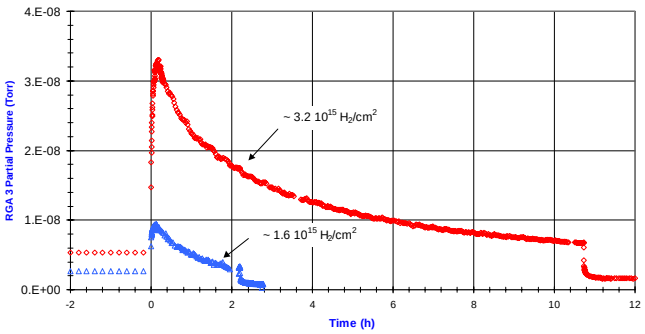

Figure 4 : H_2 recycling photodesorption.

3.3 Absence of pumping holes

The experiment depicted in 3.1 was repeated with an OFE Cu liner without pumping holes. Fig. 5. compares the increase of hydrogen pressure for a perforated liner and a liner without holes whose temperatures are 19 K and 5 K respectively; the cold bore temperature being 3.5 K in both cases. It can be seen that the H_2 pressure for the liner without holes increases up to 10^{-9} Torr where it is stabilised by the unavoidable remaining parasitic pumping of the cold bore, for example near the chimney. As demonstrated, liner holes are efficient to maintain the pressure below the value defined by $\eta\Gamma/C$ where η is the primary photodesorption yield, Γ is the

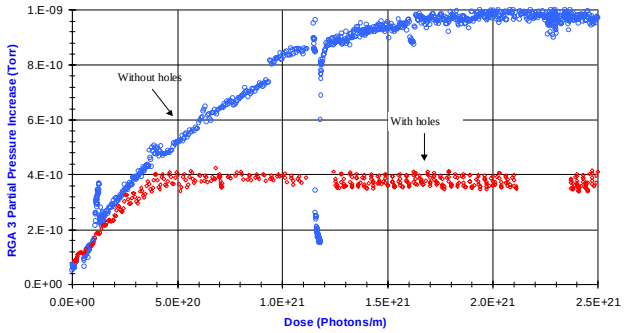

Figure 5 : Comparison of the H_2 photodesorption between a liner with and without pumping holes.

photon flux and C the pumping speed of the holes [5].

4 RESULTS IN THE EPA RING

4.1 Beam induced heat load

The heat load onto the liner was measured by its warm up without active cooling. Static loads onto the liner are ~ 0.5 W. Dynamic loads of ~ 0.6 W(~ 0.5 W) for electrons(positrons) were measured for 8 bunches of 5 10^{10} particles.

The heat load onto the cold bore was measured by the boiloff method. Dynamic loads of less than 0.1 W were observed for electron and positron beams.

4.2 Photodesorption with electron beam

For electrons, SR induced molecular desorption for H_2 could be observed as shown in Fig. 3. However, the level of CO during this run was considerably higher than that of H_2. It is not clear whether this observation could be attributed to a parasitic effect or to the unattenuated low energy photons with respect to the SR spectrum of the beam line. More studies are needed to understand this observation.

5 IMPLICATION TO LHC DESIGN

The experiments presented here clearly demonstrate the usefulness and effectiveness of the pumping slots in the beam screen to control the gas density.

However, the design of the beam screen slots should be carefully chosen. Indeed, the yields of Table. 1 give a total beam life time of ~ 70 h for the baseline design of the beam screen (4.4 % transparency and a Clausing factor of 0.7). The reduction of photodesorption yield with dose during the initial phase of operation is necessary to reach the nominal vacuum requirements. However, any additional ion and/or electron induced molecular desorption will make the situation less confortable and should also be taken into account.

Due to the large recycling yield of H_2, its surface coverage should be minimised prior to injecting proton beams. For instance, since a few monolayers of H_2 are expected to be produced and condensed onto the cold bore during operation, a warming up of the cold bore during a quench requires a controlled procedure to assure a clean surface of the beam screen before restarting the machine.

6 ACKNOWLEDGMENTS

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