SYNCHROTRON RADIATION STUDIES OF THE LHC DIPOLE BEAM SCREEN WITH COLDEX

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Abstract

The cold bore experiment (COLDEX) installed in a beam line of the electron-positron accumulator (EPA) at CERN, has been used to study the effect of synchrotron radiation onto the LHC dipole beam screen. The ~ 2 m long cryostat, that can be cooled below 3 K, is fitted with an actively cooled beam screen. A 'sawtooth' copper co-laminated type beam screen has been submitted to grazing synchrotron radiation with 194 eV critical energy. Experiments studying the effect of photon dose, gas condensation onto beam screen or cold bore and temperature oscillations is presented. Implications to LHC operation is discussed.

1 INTRODUCTION

The vacuum envelope of the cryogenic elements of the Large Hadron Collider (LHC) will be fitted with a perforated beam screen (BS) to protect the cold bore vacuum chamber (CB) against heat load induced by the 7 TeV proton beam and to provide a distributed pumping to assure a 100 h beam life time. In the arcs, the circulating beam will generate an intense synchrotron radiation (SR) flux of 10^{17} photons/m/s with a critical energy of 45 eV. The photoelectrons produced will in turn be accelerated by the beam depositing power onto the BS and creating secondary electrons which might be accelerated again by the successive bunches. The result of this process will be the build up of an electron cloud.

Since the operation of the machine will be strongly limited by the electron cloud power deposition [1, 2], it is essential to limit this phenomenon. The source of photoelectrons will be minimised by a sawtooth structure [3] which reduces the photoelectron yield to ~ 0.02 e/ph and the forward reflection to ~ 6 % avoiding the increasing of the photon fan [4]. Among several means to reduce the secondary electron yield (SEY), electron bombardment due to the electron cloud itself, seems to be one of the most promising [5]. A SEY of ~ 1.2 was obtained from a copper co-laminated sample after an accumulated electron dose of 10^{-2} C/mm^2 [4]. At the end of this scrubbing period the electron multiplication will be strongly reduced and the remaining heat load may be due to the photoelectrons only.

During the scrubbing period, for a heat load budget of ~ 0.22 W/m and a cloud energy of 100 eV, the electron flux could be as high as $1.4 \ 10^{16}$ electrons/m/s *i.e.* 7 % of the SR flux. But, since the electron stimulated desorption (ESD) yield could be 100 times higher than the photon stimulated desorption (PSD) yield the gas load will be dominated by ESD. At the end of this period , about 10 monolayers of gas will have been desorbed from the more than 100 monolayers available [6]. When the surface will be scrubbed, the gas load will be due to PSD and ESD via photoelectrons in about equal quantities.

It is therefore of great importance to measure the PSD yields of the LHC BS material. For this reason, the COLDEX cryostat was fitted with a perforated sawtooth BS (transparency ~ 1%) made of copper co-laminated stainless steel, the LHC base line material.

2 EXPERIMENTAL SET UP

The cold bore experiment (COLDEX) is a cryostat which simulates a LHC type vacuum system. The apparatus was installed in a beam line of the electron-positron accumulator (EPA) and subjected to SR at a grazing angle of 11 mrad [7]. The SR flux, $\dot{\Gamma}$, equals $3.4 \ 10^{16}$ photons/m/s *i.e.* ~1/3 of the LHC dipole SR flux with 194 eV critical energy. The light produced in the EPA bending magnet was collimated and thus attenuates the SR spectrum below 4 eV.

The COLDEX cryostat is made of two concentric chambers, the inner one is a demountable BS and the outer one a double wall stainless steel vacuum chamber which mimics the LHC CB. The temperature of the BS can be controlled from 5 to about 100 K via helium gas. When the CB vessel is filled with liquid helium it can be pumped allowing a temperature control from 2.5 to 4.2 K. The pressure is measured in the centre of the apparatus via calibrated total and partial pressure gauges (RGA 3). A copper chimney, at room temperature, is fitted at ~ 1 mm from the BS measurement port. It prevents from the parasitic physisorption of the desorbed species. The vacuum system was cleaned according to UHV standard. Prior the measurements, all the beam line, except the cryostat, was baked.

3 RESULTS

3.1 Long term irradiation

The CB was first cooled down to 2.7 K followed by the BS to 7 K. Figure 1 shows the variation of the partial pressure increase versus the photon dose. The base pressure measured with beam off at the end of the run was subtracted to the partial pressure measurement. The total photon dose was ~ $2.7 \ 10^{22}$ photons/m (~ 10 days of LHC operation at 1/3 nominal beam current). During irradiation, the downstream valve was closed without consequence on the pressure reading in RGA 3

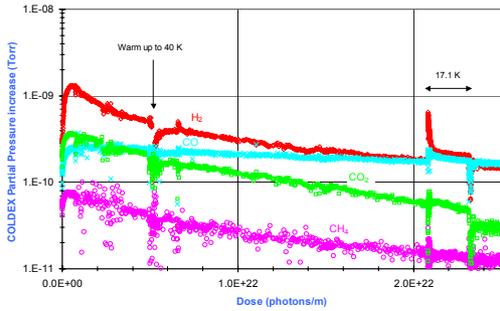demonstrating that the COLDEX could be considered as an infinite tube.

Figure 1 : Long term irradiation of a copper co-laminated sawtooth BS.

At the start of irradiation, a strong H_2 pressure increase is observed due to its large recycling yield. The equilibrium is reached when the recycling effect is exactly balanced by the pumping onto the BS. From this time, the H_2 pressure is directly proportional to the primary photodesoprtion yield, η and the holes pumping speed, C :

$$P_{H2} = \frac{\eta}{C} \dot{\Gamma} \qquad (1)$$

Afterwards, the observed decrease in pressure is due to the conditioning process under photon irradiation. At $5\ 10^{21}$ photons/m, the BS temperature was raised, while the beam was off, to ~ 40 K to desorb all the gases except CO_2. Restarting irradiation shows again a significant recycling effect followed by an equilibrium pressure. From $2\ 10^{22}$ to $2.3\ 10^{22}$ photons/m the BS temperature was raised to 17 K. After the transient due to the recycling effect, a similar equilibrium pressure is observed. Also, the H_2 primary photodesorption yield is constant in the 7 to 17 K temperature range.

The behaviour of the other gases is different from the H_2 since their recycling yield is ~ 1/1000. The time to reach equilibrium is by far too large and the measured pressure is given by :

$$P = \frac{\eta + \eta'}{\sigma S + C} \dot{\Gamma} \approx \frac{\eta + \eta'}{\sigma S} \dot{\Gamma} \qquad (2)$$

Where σS is the BS pumping speed and η' the recycling photodesorption yield.

As shown, the pressure of CH_4 and CO_2 decrease with photon dose but the CO pressure is almost constant. This effect could be attributed to CO_2 photocracking as observed in [8] and predicted in [9].

3.2 Cleaning rate and PSD yield

The variation of the primary photodesorption yield versus photon dose, D, is usually expressed with:

$$\eta(D) = \eta_0 \left(\frac{D}{D_0}\right)^{-a} \qquad (3)$$

Table 1 shows the yields measured at a dose of 10^{22} photons/m and the cleaning rate, a. It is concluded

that more than 10 years of nominal operation will be required to remove 100 monolayers of all the gases.

Table 1 : Primary, recycling photodesorption yield measured at 10^{22} photons/m and cleaning rate

	H_2	CH_4	CO	CO_2
η	$2\ 10^{-4}$	$> 6\ 10^{-6}$	$> 3\ 10^{-5}$	$> 2\ 10^{-5}$
$(\eta+\eta')/\sigma$	$2\ 10^{-2}$	$6\ 10^{-4}$	$3\ 10^{-3}$	$2\ 10^{-3}$
a	0.6	0.6	0.2	0.8

At the end of the SR exposure, the BS was raised to room temperature (RT) for a short irradiation ($3\ 10^{18}$ ph/m) and cooled back to 7 K. The reduction by a factor two for the H_2 PSD yield demonstrates that the RT irradiation is more effective to scrub the surface.

3.3 Sawtooth structure

The purpose of the sawtooth is to ensure that the SR irradiates the surface at perpendicular incidence. The SR power incident onto a BS could be measured for OFE copper BS and sawtooth copper co-laminated BS. It was found that, respectively, in agreement with published data [3, 4], ~ 40 % and ~ 5 % of the incident power was reflected in the forward direction.

3.4 Temperature oscillations

To study the effect of potential temperature oscillations, the BS temperature was varied at the end of the long irradiation period. Figure 2 shows that, in the case of "low" surface coverage, temperature oscillations around 20 K and 25 K liberates H_2 and CO respectively. To meet the 100 h beam life time equivalent at 300 K to ~ 10^{-8} Torr and 10^{-9} Torr for H_2 and CO, oscillations around ~ 25 K should be avoided.
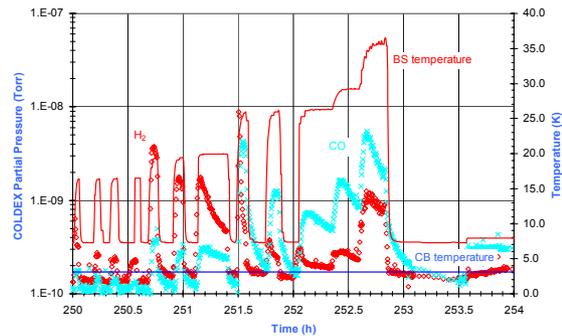

Figure 2 : Temperature oscillations.

3.5 Thick layers of gases

During operation of the machine, the gas will be physisorbed onto the BS or CB. Since the H_2 recycling yield is high, most of it will be physisorbed onto the CB whereas the other gas species will be physisorbed onto the BS due to their low recycling yield.

Figure 3 shows the effect of a pre-condensed layer of H_2 prior to irradiation at 5.5 K. During operation, this large coverage could be inferred to the cooling of the BS first after a magnet quench. For surface coverage of about 1 monolayer, several hours of irradiation are required to reach a pressure below 10^{-8} Torr.
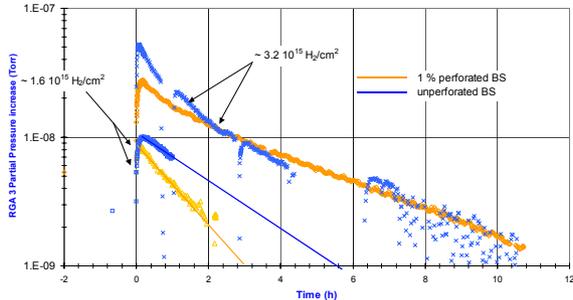

Figure 3 : Thick layers of H_2 in the case of perforated and unperforated BS.

To simulate the running of ~ 500 h of LHC at nominal operation, 10 monolayers of hydrogen were injected onto the COLDEX CB. Whilst the CB was held in the 2.5 to 4.2 K range, the BS temperature was varied from 5 to 100 K with the BS subjected or not to SR. During these studies, no significant H_2 pressure increase were detected indicating that the effect of reflected photons and BS temperature onto the CB is negligible.

The effect of thick layers ($\sim 8.5 \ 10^{15}$ molecules/cm^2) of CO and CH_4 was studied with a BS without holes operating at 6 K. Figure 4 shows that, due to the low recycling yield, several hours are required to remove the CO to a comfortable level.
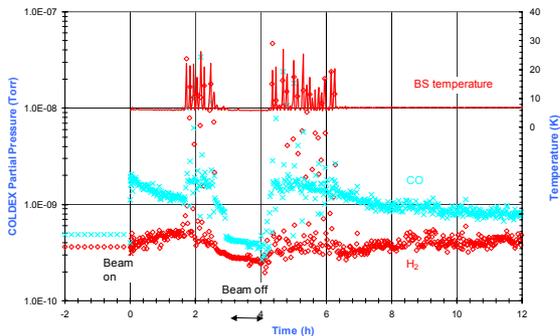

Figure 4 : $\sim$ 10 monolayers of CO condensed onto a BS without hole prior to irradiation at 7 K

Figure 5 shows that, contrary to CO, the condensed CH_4 is photocraked into H_2 as demonstrated by the large H_2 pressure increase. Similar results are obtained with CO_2 which is photocraked into CO and O_2.
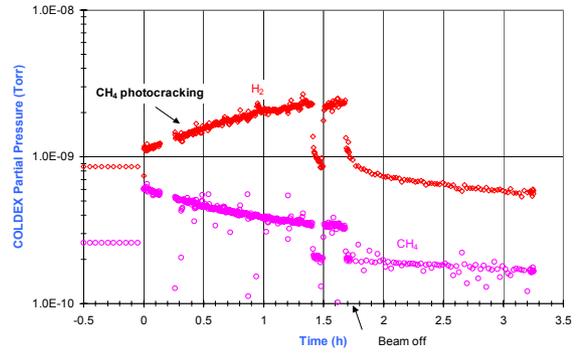

Figure 5 : $\sim$ 10 monolayers of CH_4 condensed onto a BS without hole prior to irradiation at 6 K

4 CONCLUSIONS

Long term irradiation from which PSD yield and cleaning rate of the current LHC base line material has been presented. Room temperature PSD was found to be more efficient to reduce the yield (higher conditionning rate). The sawtooth structure was shown to effectively reduce the photons forward reflectivity. At low surface coverage, temperature oscillations around 25 K should be avoided to limit the CO desorption. Careful cooling down of the BS should be performed to avoid condensation of thick layers of H_2 and CO specifically. The CB was shown to be efficient to maintain large coverage of H_2 during machine operation.

5 ACKNOWLEDGEMENTS

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