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CRYOSORBER STUDIES FOR THE LHC LONG STRAIGHT SECTION BEAM SCREENS WITH COLDEX

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

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The cold bore experiment (COLDEX), that can be cooled below 3 K, has been fitted with a ~ 2 m long actively cooled beam screen equipped with cryosorber to simulate the LHC Long Straight Section (LSS) beam screens. Effects of both synchrotron radiation at grazing incidence with 194 eV critical energy and gas injections have been studied. Results as a function of temperature, gas species and gas coverage are presented. Possible implications to LHC LSS design and operation are discussed.

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Abstract

The cold bore experiment (COLDEX), that can be cooled below 3 K, has been fitted with a ~ 2 m long actively cooled beam screen equipped with cryosorber to simulate the LHC Long Straight Section (LSS) beam screens. Effects of both synchrotron radiation at grazing incidence with 194 eV critical energy and gas injections have been studied. Results as a function of temperature, gas species and gas coverage are presented. Possible implications to LHC LSS design and operation are discussed.

1 INTRODUCTION

The Large Hadron Collider (LHC) will bring into collision 7 TeV proton beams. Around the 27 km ring, 8 Long Straight Section (LSS) will be distributed, 4 for the particle physic experiments, 2 for momentum and betatron cleaning, 1 for RF cavities and 1 for beam dumps. In the current design of the LSS, some cryoelements operate at ~ 4.5 K and others at 1.9 K.

Similarly to the arc dipole, with a cold bore (CB) operating at 1.9 K, all cryoelements, except the RF cavities, should be equipped with perforated beam screens (BS) to provide vacuum stability and ensure the required vacuum level.

However, cryoelements operating at 4.5 K cannot pump more than a monolayer of H_2 since the saturated vapour pressure (~ 10^{-6} Torr) will be too high for the circulating beams. Thus, it is proposed to add cryosorbers onto the BS. These cryosorbers should have a sufficiently large pumping speed and capacity, operate in the 5 to 20 K region in an accelerator environment. To allow a regeneration, these cryosorbers should be located on the external surface of the temperature controlled BS. Activated charcoal was selected as a candidate cryosorber since it meets the above requirements.

The cold bore experiment (COLDEX) cryostat was fitted with a perforated BS equipped with activated charcoal subjected to synchrotron radiation (SR) and gas injection to simulate the behaviour of such a BS in the LHC LSS.

2 EXPERIMENTAL SET UP

During the vacuum study of the performance under SR, COLDEX was installed on a beam line of the Electron Positron Accumulator (EPA) [1]. The EPA SR was incident at 11 mrad with a flux of ~ 3.4 10^{16} photons/m/s and 194 eV critical energy. In the LSS, the photon flux is about 10^{16} photons/m/s, very low grazing angle and 1 to 20 eV critical energy [2].

During the injection studies, COLDEX was installed in the laboratory. A copper injection line was inserted into the BS to simulate a longitudinal gas load. This line was designed to operate at ~ 150 , minimise the longitudinal flux drop (< 20%) and offer a good azimuthal injection uniformity in the case of low effective sticking coefficient.

The COLDEX apparatus is a tool to simulate, as closely as possible, the vacuum behaviour of a LHC cryoelement. It is made of two concentric chambers, the inner one is a demountable BS and the outer one being the vacuum vessel which mimics the CB. The BS temperature can be controlled from 5 to about 100 K via helium gas flow through cooling tube. The CB is a double vessel which can be filled with liquid helium and thus can be temperature controlled from 2.5 to 4.2 K.

The BS (2.2 m long and 47 mm inner diameter) is made of OFE copper and has 1 % of it surface with pumping holes. Activated charcoal was glued with an epoxy resin onto 10 mm wide copper plates. Two plates were screwed to the external face of the BS. The specific area of activated charcoal was 206 cm^2/m. Figure 1 shows a cross section view of the CB and BS injection line assembly. As for a cryopump, care was taken to avoid plugging of the cryosorber by gases other than H_2. By construction, all the molecules, except H_2, desorbed or injected into the BS can be physisorbed in either the external side of the BS or the CB. Indeed, when the H_2 vapour pressure is too high, the molecules bounces and migrates towards the activated charcoal where they are pumped.

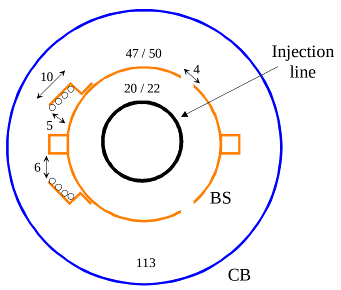

Figure 1 : Section of the CB, BS and injection line assembly

3 SR IRRADIATIONS

The SR irradiations were performed with several combinations of BS and CB temperature, 5 to 30 K, 4.5 and 80 K respectively, for different surface coverages of H_2 and CO in the 1 to 100 monolayer range.

3.1 Bare surface

The first irradiations were performed with a bare surface. Whilst the BS was at 5 and 30 K the CB was at 4.5 K or 80 K. Figure 2 shows the evolution of the H_2 pressure for different BS temperatures with the CB at 4.5 K. As expected from previous studies, when irradiated at 5 K, a strong H_2 pressure increase, due to the recycling effect, followed by an equilibrium is observed [1]. After 20 h, the BS temperature was raised to ~ 30 K and the irradiation started at 22 h. A rapid H_2 pressure increase is observed followed by an equilibrium at ~ 3.5 10^{-10} Torr. The higher equilibrium level at ~ 30 K is attributed to the fact that the outer part of the BS no longer pumps.

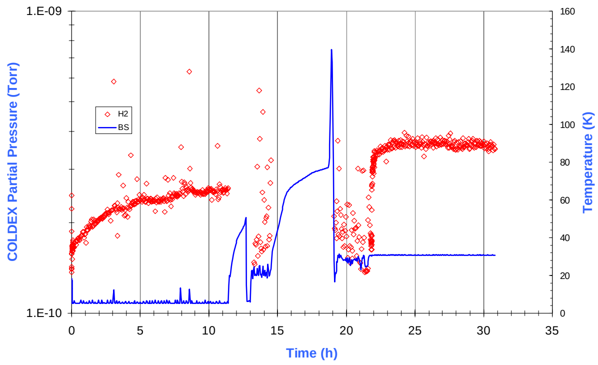

Figure 2 : Irradiation of a bare BS at 5 and 30 K.

Similar experiments were performed with the CB at ~ 80 K. Again, at 5 K, the recycling effect was observed, and at 30 K, a pumping was still observed. This pumping can only be attributed to the activated charcoal. The equilibrium at ~ 6 10^{-10} Torr indicates a negligible pumping speed degradation in the BS-CB space.

3.2 Thick layers and temperature oscillations

To simulate the effect of gas load due to photon and electron stimulated desorption in the LSS, several injections of gas were made. For this purpose, the valves were closed, the CB warmed to ~ 80 K and the injection performed with the BS at ~ 25 K. Since the injection was made from one end of the COLDEX, the BS temperature was raised ~ 40 K to allow a redistribution of gas and a uniformisation of the pressure in the system , a few 10^{-6} Torr. After a few minutes, the BS temperature was then slowly cooled back to the desired temperature. The drawback of this procedure is that the injected gas, which is intentionally pumped onto the cryosorber, could diffuse into the activated charcoal during the process. In turn, the physical binding of the gas with the cryosorber will be higher and the system will be less sensitive to the temperature.

One monolayer (3 10^{15} H_2/cm^2) was injected and the irradiation was performed with the CB at ~ 4.5 K and the BS temperature was varied in the range 5 to 30 K. The H_2 pressure level remained below 5 10^{-10} Torr.

Figure 3 shows the behaviour of the system after injection of 10 monolayers of H_2. During this experiment, the CB was at ~ 4.5 K and the BS at ~ 27 K. Temperature oscillations were applied with a total amplitude of ~ 8 K leading to the observed spread in pressure. The data show that there is an initial pressure increase due to the beam but after 4 hours of irradiation, the H_2 level is similar to the level before irradiation *i.e.* below 2 10^{-9} Torr.

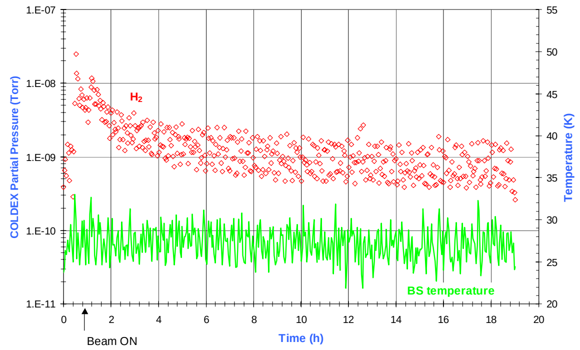

Figure 3 : Irradiation after injection of 10 monolayers of H_2 with the BS at ~ 27 K and the CB at ~ 4.5 K.

Finally, 100 monolayers of H_2 were injected into COLDEX. Figure 4 shows the result of temperature oscillations during irradiation whilst the CB was at 4.5 K and the BS at ~ 29 K. The temperature oscillation amplitude was about 8 K. Either while the beam was on or off, the H_2 was above 10^{-8} Torr and increased up to 5 10^{-7} Torr. Since the 100 h beam life time limit for the LHC, is 10^{15} $H_2.m^{-3}$ (~ 10^{-8} Torr at room temperature). Clearly, the LHC could not run at such a high coverage for such a temperature without regeneration of the system.

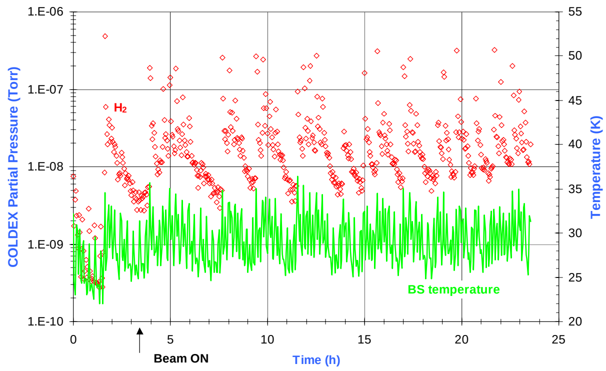

Figure 4 : Irradiation after injection of 100 monolayers of H_2 with the BS at ~ 29 K and the CB at ~ 4.5 K.

A similar experiment was performed with a BS operating at ~ 19 K with again ~ 8 K of oscillation amplitude. In this case, the H_2 pressure remained below 10^{-8} Torr.

3.3 CO plugging

To estimate the efficiency of CO plugging, 10 monolayers of CO were injected into COLDEX, followed by 10 monolayers of H_2. An irradiation similar to the one depicted in figure 3 was performed and gave almost identical results showing that a pre-condensed layer of 10 monolayers of CO does not block the sites for H_2.

4 REGENERATION

Thermal desorption spectroscopy indicates a H_2 desorption peak at ~ 60 K *i.e.* a binding energy of ~ 185 meV. Regeneration of the activated charcoal will require the possibility to warm up the BS at least up to 75 K to remove ~ 80 % of the condensed gas.

In the case of CO, the desorption peak is at ~ 110 K *i.e.* a binding energy of ~ 370 meV. Regeneration of the activated charcoal due to CO contamination will require the possibility to warm up the BS above 110 K.

5 GAS INJECTION

Gas injections were performed with H_2 and CO for the BS operating from 5 to 40 K and the CB at 4.5 or 140 K.

Hydrogen injection experiments, performed with a flux of 2 10^{-5} Torr.l/s *i.e.* ~ 10 times the LHC gas load due to photon stimulated desorption in the arcs, shows an equilibrium level in the range 7-9 10^{-9} Torr for BS temperature below 33 K and a CB operating at 140 K. Above 40 K, a clear degradation of the pumping speed of the activated charcoal was noticed.

Other injections illustrates the competition of the pumping between the BS and the activated charcoal. Figure 5 shows this competition for a BS successively operating at 15, 20 and 30 K while the CB was maintained at 5 K.

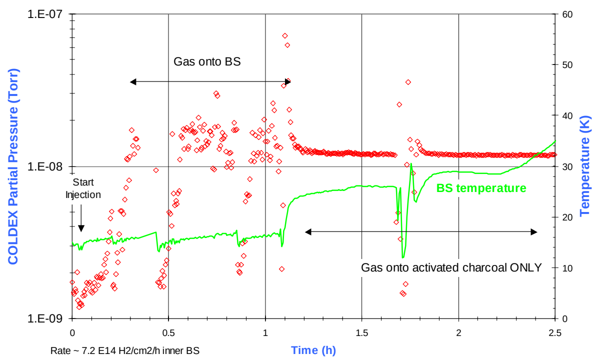

Figure 5 : Illustration of the pumping competition between BS/CB and activated charcoal

Pressure oscillations due to the transfer of gas from the BS to the activated charcoal are observed when the BS operates at 15 K. Above 20 K, no H_2 is pumped anymore onto the BS and the injected gas is pumped directly onto the activated charcoal via the BS holes.

CO gas injection with a flux of ~ 100 times the gas load due to photon stimulated desorption in the LHC arcs were performed. The CO level was maintained below the 100 h life time limit when the BS temperature was varied between 20 K to 35 K whilst the CB was at 140 K.

6 CONCLUSIONS

In the context of the LHC LSS, studies with synchrotron radiation and gas injection of a BS with a cryosorber have been presented. Activated charcoal was shown to be efficient to maintain a reasonable vacuum for a BS operating at 20 +/- 5 K :

- up to 100 monolayers of H_2 could be pumped which correspond to 750 monolayers onto the activated charcoal in the geometry used (206 cm^2/m).
- plugging was not observed by a pre-condensation of 10 monolayers of CO and the activated charcoal could subsequently adsorb, at least, 10 monolayers of H_2.

Thermal desorption spectroscopy showed that adsorption sites are for H_2 at ~ 60 K *i.e.* 185 meV and for CO at ~ 110 K *i.e.* 370 meV. H_2 regeneration of the activated charcoal will require the possibility to warm up the BS to ~ 75 K.

For a BS with 1 % transparency, the activated charcoal was shown to pump up to ~ 40 K without degradation of the hole pumping speed.

A competition in terms of pumping speed between the BS and activated charcoal was shown in the range 10 to 20 K. In this temperature region, pressure rises might be observed when sudden temperature rises or temperature oscillations occurs.

More work are required to implement such material in the LSS. For reason of radiation hardness, glue used for the cryosorber attachment might be undesirable. The consequences of the thermal anchoring quality should be investigated. Activated charcoal could be a dust “factory” which might be undesirable in an accelerator environment. For this reason, other cryosorbing materials could be tested.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] V. Baglin *et. al.* Proceeding of EPAC’00, Vienna, June 2000.

[2] O. Malyshev *et. al.* LHC Project Note 274, December 2001.