Experimental Investigation of Dynamic Pressure in a Cryosorbing Beam Tube Exposed to Synchrotron Radiation

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Abstract

Results of photodesorption experiments on a 4.2-K beam tube irradiated with synchrotron radiation from the VEPP-2M storage ring are being reported. The experiments have been performed on SSC1 and SSC2 beamlines. Synchrotron radiation parameters of the SSC1 beamline are the same as the SSCL 20 TeV proton collider: critical energy = 284 eV, photon intensity $1 \cdot 10^{16}$ photons/m/s. Photon intensity of the SSC2 beamline is eight times higher than intensity of the SSC1 beamline. We have used two experimental configurations to observe the density increase due to: (1) photodesorption of tightly bound molecules not previously desorbed and (2) photodesorption of weakly bound cryosorbed molecules. The two configurations used were a simple 4.2-K beam tube and a 4.2-K tube with a coaxial perforated liner. The photo-desorption coefficient of tightly bound H_2 measured on the SSC1 beamline was observed to decrease monotonically with photon exposure, reaching η $4 \cdot 10^{-4}$ molecules per photon at the end of exposure ($\sim 1 \cdot 10^{22}$ photons/m). The same experiment on the SSC2 beamline gave a similar result at photon dose $3.5 \cdot 10^{22}$ photons/m. The photodesorption coefficient of cryosorbed H_2 increased with increasing H_2 surface density, reaching η'/σ_w ~ 7 molecules/photon at one monolayer surface density $(s_m \sim 3 \cdot 10^{15}$ $H_2/cm^2)$, where σ_w is the sticking coefficient. The liner was shown to effectively shield cryosorbed molecules from synchrotron radiation.

1. INTRODUCTION

Density increase in the beam tube due to photon-simulated desorption (PSD) can be a problem for achieving desirable beam current and lifetime in the SSCL 20 TeV proton Collider. The molecular density inside a cryosorbing beam tube has three components: (1) the photodesorbed tightly bound molecules, (2) the photodesorbed physisorbed molecules and (3) the thermally desorbed isotherm density of physisorbed molecules [1]. For gases other than H_2 (and He if there are leaks) the isotherm density is negligible. The potential problems of the simple beam tube—photodesorption of physisorbed molecules and the H_2 isotherm density—are

alleviated by the liner concept. The liner is a coaxial perforated tube fitting inside the magnet bore tube. Physisorbed molecules accumulate behind the liner and out of the view of the photons. The effective surface area of the magnet bore tube can be increased many times by the addition of cryosorbing material behind the liner, thus postponing increase of the H_2 isotherm density.

2. EXPERIMENTAL SETUP

The experiments were performed on two synchrotron radiation beamlines SSC1 and SSC2 of the VEPP-2M electron-positron storage ring at Budker Institute of Nuclear Physics (BINP) in Russia. The schematic of these experiments is shown in Figure 1. The details and parameters of the beamlines were described previously [2]. The photon-critical energy and intensity of the SSC1 beamline are the same as the SSC (284 eV, ~$1 \cdot 10^{16}$ photons/m/s). Photon intensity of the SSC2 beamline is eight times higher than intensity of the SSC1 beamline. The simple beam tube and bore tube liner were 1-m-long sections of electrodeposited Cu on SS tube (ID = 32 mm, OD = 34.9 mm, Cu thickness = 70 μm). The liner was perforated with 600 2-mm-diameter holes spaced 1 cm axially and 60° azimuthally. The bore tube outside the liner was SS (ID = 41.9 mm, OD = 44.5 mm) welded to the liner with annular rings at the ends. The simple beam tube and the liner bore tube were in turn welded into a horizontal LHe cryostat (~20 l LHe) and formed the interface between LHe and vacuum. An intermediate 140-liter-volume tank was installed on the top of the horizontal cryostat. This setup allowed the experiments to be performed for indefinite periods of time without interruption at 4.2-K by adding LHe to the tank from a transport dewar. The static 4.2-K heat load was about 0.45 W. This low static heat load allowed measurement of the synchrotron radiation power hitting the beam tube by noting the increase in He boil off rate. The value obtained confirmed the calculated value. The temperature of the bore tube could be reduced to 2.5–3K by pumping on the LHe. The temperature was measured by a semiconductor gage installed on the outer wall of the bore tube. The temperature of the liner was not measured. We estimate the temperature rise at the center of the liner to be 5–10 K above the LHe temperature when exposed to a photon intensity of 125–250 mW/m.
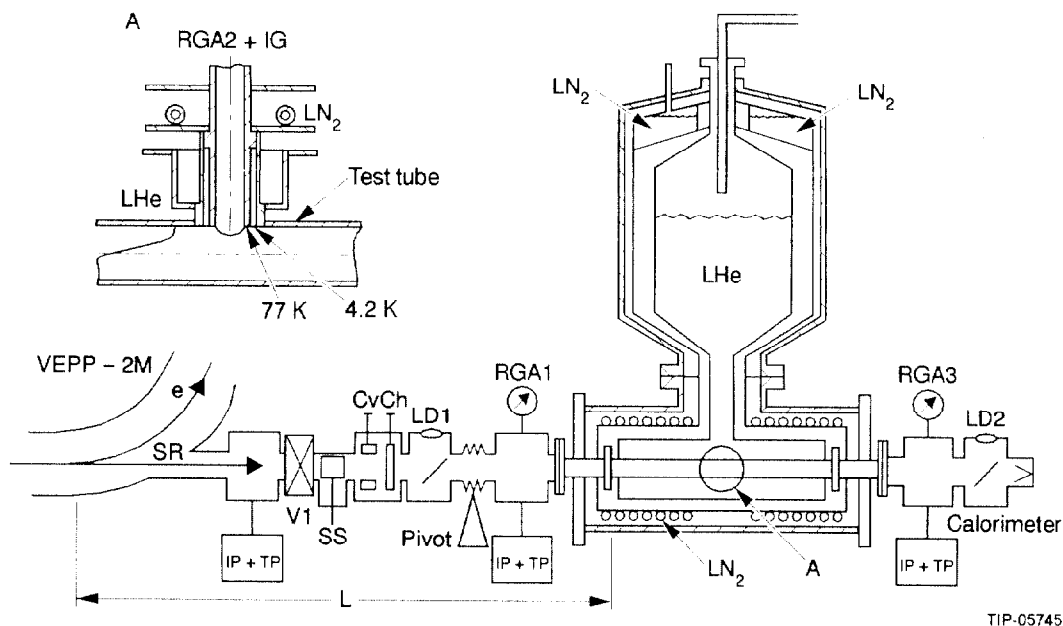
Figure 1. Experimental setup for cold beam tube experiment. V1 - vacuum valve; Cv, Ch - vertical and horizontal collimators; SS - safety shutter; LD1, LD2 - phosphors; IG - ion gage; RGA - residual gas analyzer; IP+SP - combination ion and Ti sublimation pump; L_{SSC1} = 11 070 mm; L_{SSC2} = 1750 mm.

Gas densities were measured with calibrated rf quadrupole residual gas analyzers (RGAs) at room temperature. An RGA was connected to the center of the beam tube and at each warm end. The center RGA viewed the beam tube through a 2.4-cm-diameter hole. Care was taken to avoid 4.2-K cryosorbing surfaces in the tube connecting the RGA to the beam tube. The connecting tube had a temperature of 77 K at the beam tube hole and made a transition through thin SS bellows to 294 K at the RGA. An annular vacuum gap of ~0.2 mm separated the 77-K viewing tube from the 4.2-K beam tube. Thin-wall SS bellows were used at the ends of the 4.2-K beam tube for transitions to 77 K and 294 K. The 294-K vacuum ends of the cryostat were pumped with combination ion and titanium sublimation pumps.

3. DISCUSSION OF THE DATA

The H_2 dynamic density increase in the center of the tube is shown versus integrated photon flux in Figure 2. The curves A and B in this figure are obtained from non-liner experiments and the curves C and D from liner experiments. The A, B and C experiments have been performed on the SSC1 beamline, and the experiment D on the high intensity SSC2 beamline. The dynamic density of H_2 is shown assuming that the mean molecular speed corresponds to 4.2 K. This is a lower bound for the real molecular speed and thus the dynamic density in Figure 2 is an upper bound. The real molecular speed is unknown because the pressure in the experiments was measured by the RGA at room temperature. The measured quantity was $n \cdot v$, where n is the

molecular gas density and $\bar{v}$ the effective mean molecular speed. The line E shows upper limit of H_2 density $3 \cdot 10^8$ 1/cm^3 in the Collider beam tube to provide the desired vacuum limited luminosity lifetime of 150 hours. Recently we have begun to make progress directly measuring the molecular density inside the 4.2-K beam tube using charge exchange reactions of a proton beam. These measurements are described in a companion paper [3].

The dynamic density of H_2 in the beam tube without a liner (A, B Figure 2) increases rapidly with integrated photon flux and due to photodesorption of an increasing surface density of physisorbed molecules. This density can be expressed by following formula:

$$ n = \frac{4\eta' \Gamma}{\sigma_w A_w \bar{v}} $$ (1)

where Γ = photons/m/s; σ_w is the sticking coefficient, A_w the beam tube wall area per unit length; $\bar{v}$ the effective mean molecular speed; n the dynamic molecular gas density, and η' the desorption coefficient of the physisorbed molecules (recycling coefficient). The η' coefficient for low surface coverage can be expected to depend linearly on the H_2 surface density and can reach a value of the order of unity at one monolayer $s_m \sim 3 \cdot 10^{15}$ H_2/cm^2 [4]. It is being seen from the plot that the H_2 density in the simple bore tube becomes higher than required density (E) after $2 \cdot 10^{20}$ photons/m. This is only about 6 hours of SSC operation.
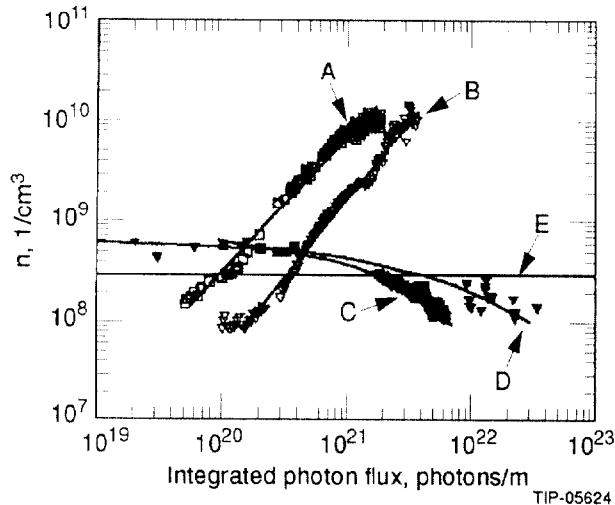
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Figure 2. Dynamic H_2 density measured at the center of the beam tube with and without liner. The density is normalized to $1 \cdot 10^{16}$ photons/m/s.

In the liner experiments (curves C and D, Figure 2) the behavior of H_2 dynamic density is similar for both runs. The same tube was used for both experiments with an intervening exposure to atmosphere. One can see that the beam tube apparently did not retain a memory of its previous conditioning when exposed to atmosphere. However the four times higher photon intensity in the second experiment and related increase in beam tube temperature require a more careful investigation of this point. The density decreases from $4 \cdot 10^8$ $1/cm^3$ in the beginning of the experiment to $4 \cdot 10^7$ $1/cm^3$ at $3.5 \cdot 10^{22}$ photons/m. With the perforated coaxial liner, physisorbed molecules accumulate behind the liner, where they are shielded from the photon flux, and the H_2 density is predominantly due to desorption of tightly bound molecules. To avoid influence of the thermal desorption of physisorbed molecules from the bore tube as one monolayer is approached the temperature of this tube was lowered to 2.5–3 K by pumping on the LHe.

The dynamic density in the liner configuration is determine by the following expression:

$$n = \frac{4\eta\Gamma}{pN_hA_h\bar{v}} \qquad (2)$$

where η is the desorption coefficient of tightly bound molecules, N_h the number of holes per meter, A_h the area of the holes. p is the molecular transmission probability through a hole. The coefficient η is equal to $4 \cdot 10^{-3}$ mol/photon at the beginning of the experiment and decreases to 4–$7 \cdot 10^{-4}$ mol/photons at the end. The density becomes lower than required for luminosity lifetime at $\sim 1 \cdot 10^{21}$ photons/m. The photodesorption of other gases heavier than H_2 – CO, CO_2 and CH_4 – must also be considered for obtaining the required luminosity lifetime in a liner configuration. We have some information on CO and are modifying the apparatus to allow measurement of CO_2 and CH_4 as well.

Additional details of the cold photodesorption experiments are contained in references [5] and [6].

4. CONCLUSIONS

Based on the results of the experiments we make the following conclusions.

In the experiments reported here a simple 4.2-K beam tube does not provide the gas density required for SSCL Collider operation and the frequency of beam tube warm ups implied to keep the beam tube density within the allowable range would be inconveniently large. On the other hand the 4.2-K liner experiment achieved the required vacuum density after only a short conditioning period. The gas density in a liner configuration depends only on the desorption coefficient of the tightly bound gas and not on the desorption coefficient of gas physisorbed to the liner. The measured photodesorption coefficient changes from $4 \cdot 10^{-3}$ mol/photon at the beginning of experiment to 4–$7 \cdot 10^{-4}$ at the end of experiment 1–3.5×10^{22} ph/m.

5. ACKNOWLEDGMENTS

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