PHOTODESORPTION PROCESSES IN A VACUUM CHAMBER WITH CRYOSORBING WALLS

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Abstract.

In the beginning of 90th three project of next generation supercollider have been started. One of the important problems is to predict the residual gas density inside vacuum chamber inside cold bore of superconducting magnets at liquid helium temperatures. There existed limited data and the real necessity for detail experimental study. In 1993 the studies of photon stimulated desorption in vacuum chamber with cryosorbed wall had been started at the Budker Institute of Nuclear Physics in collaboration with SSCLab. It was shown that the gas density inside the vacuum camber with cryosorbing walls consists of three parts: (1) primary photodesorption of gas, (2) photodesorption of molecules cryosorbed on vacuum chamber walls and (3) thermal desorption (equilibrium pressure). The model describing these processes and the experimentally defined unknowns of that model are presented.

1. Introduction

Development of accelerator technology in the field of high-energy hadrons has met the necessity to use of superconducting magnets. Next generation supercollider (LHC in CERN [1], SSC in USA [2]) should be first where synchrotron radiation (SR) from relativistic hadrons becomes significant. Photon-stimulated gas desorption can be a serious problem in achieving desirable vacuum inside a collider's beam tube. Vacuum chamber of these machines is mostly a cold bore inside superconducting magnets to be used at liquid helium temperatures. There existed limited experimental data [3,4] to predict the residual gas density inside cold vacuum chamber irradiated by SR. The proper design of the beam tube requires performing some special photodesorption experiments at LHe temperatures. The main parameter that must be determined is the gas density inside the cold beam tube.

The real necessity of detailed experimental study was declared at SSC Meeting in May 1992 [5]. In 1993 the studies of photon stimulated desorption in a vacuum chamber with cryosorbed walls started as a part of collaboration between SSCLab and Russia. When the SSC project was cancelled, the studies continued as a part of collaboration between CERN and Russia for the LHC. All the experiments were performed on SR beam lines of VEPP-2M storage ring at BINP. The present paper is a summary of these studies.

2. Model of photodesorption processes in a vacuum chamber with cryosorbing walls

The long term study of photodesorption processes in a vacuum chamber with cryosorbing walls at cryogenic temperatures allows to describe that process as follow. [6–15].

For a vacuum volume with initially bare surface (without pre-condensed gas) synchrotron radiation photons stimulate gas desorption from the vacuum chamber surface. That is the same effect that takes place in a room temperature vacuum chamber of accelerators. But in contrast to room temperature machines where desorbed gas is removed by external pump, in a cryogenic vacuum chamber the desorbed gas molecules will be condensed on the walls. Of course, some gas could be removed by external pumps, but for collider's vacuum chamber it is quite correct to consider vacuum chamber as on infinity long tube without external pumps. (Short tubes were studied by W. Turner [14]). Few processes influencing on the gas density in the vacuum chamber depend on the surface density of cryosorbed molecules:

- The condensed gas molecules could be again photodesorbed from and absorbed on the cold surface (recycling process). The photodesorption yield of cryosorbed molecules (so-called secondary photodesorption) depends on surface density of cryosorbed molecules. [6]
- The condensed gas molecules could be cracked by photons to other gas species. For instance, CO_2 molecules crack to CO and O_2. Due to that effect amount of CO_2 gas condensed on the walls of the vacuum chamber reduces, but that is an additional source of CO and O_2 molecules. [11]
- The equilibrium gas density should be taken in account as well, it depends on surface molecular density and surface temperature.
- The condensing process itself depends on surface molecular density and surface temperature.

Equations of gas dynamic balance inside a vacuum chamber exposed to synchrotron radiation could written as follow:

$$V \cdot \frac{dn_i}{dt} = \eta_i \cdot \dot{\Gamma} + \eta_i'(s_i) \cdot \dot{\Gamma} + \chi_i(s_j) \cdot \dot{\Gamma} - \\ - \sigma_{w_i} \cdot S_{w_i} \cdot (n_i - n_{e_i}(s_i)) - C_i \cdot n_i;$$

$$A_w \cdot \frac{ds_i}{dt} = \sigma_{w_i} \cdot S_{w_i} \cdot (n_i - n_{e_i}(s_i)) - \\ - \eta_i'(s_i) \cdot \dot{\Gamma} - \kappa_{i \to j+k}(s_i) \cdot \dot{\Gamma};$$

where the index i denotes the i-th gas species in residual gas spectrum;
n *[molecules/cm³]* is the volume molecular density;
s *[molecules/cm²]* is the surface molecular density;
V *[cm³]* is the vacuum chamber volume;
A_w *[cm²]* is the vacuum chamber wall area;
$\dot{\Gamma}$ *[photon/(sec·m)]* is the photon intensity;
η *[molecules/photon]* is the primary photodesorption yield;
η'*[molecules/photon]* is photodesorption yield of cryosorbed molecules (so-called secondary photodesorption yield);
σ_w is the sticking probability;
$\kappa_{i\to j+k}(s_i)$ *[molecules/photon]* is the cracking efficiency i-th type molecules into j-th and k-th type (i.e. how well the i-th type molecules could be cracked per photon);
$\chi_j(s_i)$ *[molecules/photon]* is the cracking yield for the j-th type molecules from the i-th type molecules, (i.e. how many the j-th type molecules could appear due to cracking of i-th type molecules per photon),
$\chi_j(s_i) = a_{j,i}\cdot\kappa_{i\to j+k}$, a = 1/2, 1, 3/2, 2, ... ;
$S_{w_i} = A_w\cdot\bar{v}_i/4$ is the ideal wall pumping speed,
$\bar{v}_i$ is mean molecular speed for the i-th gas;
C is the distributed pumping speed;
n_e*[molecules/cm³]* is the equilibrium vapour density.

Hence in the common case the dynamic gas density inside the cryogenic vacuum chamber is a function of several unknown parameters:

$$n = n(\eta_i, \eta_i'(s_i), \kappa_{i\to j+k}(s_i), \sigma_{w_i}(s_i,T), n_{e_i}(s_i,T), \bar{v}_i),$$

which should be experimentally defined for each gas species.

The following equations are written for simplification for one gas species and simple symbols without indexes are used.

A simple tube vacuum chamber: C=0

The quasi-static solution for the gas density inside a simple tube vacuum chamber with

$$V\cdot\frac{dn}{dt}\approx 0 \text{ and } A_w\cdot\frac{ds}{dt}\neq 0$$

is determined by:

$$n = \frac{\eta\cdot\dot{\Gamma}}{\sigma_w\cdot S_w} + \frac{\eta'\cdot\dot{\Gamma}}{\sigma_w\cdot S_w} + \frac{\chi\cdot\dot{\Gamma}}{\sigma_w\cdot S_w} + n_e\cdot$$

Second, third and fourth terms depend on the surface density s of the cryosorbed molecules:

$$s(t) = s_0 + \frac{1}{A_w}\cdot\int_{t=0}^{t}(\eta+\chi-\kappa)\cdot\dot{\Gamma}\cdot dt\cdot$$

A vacuum chamber with liner

The quasi-static solution for the gas density inside vacuum chamber with liner with

$$V\cdot\frac{dn}{dt}\approx 0 \text{ and } A_w\cdot\frac{ds}{dt}\neq 0$$

is determined in the common case:

$$n = \frac{\eta\cdot\dot{\Gamma}}{\sigma_w\cdot S_w + C} + \frac{\eta'\cdot\dot{\Gamma}}{\sigma_w\cdot S_w + C} + \frac{\chi\cdot\dot{\Gamma}}{\sigma_w\cdot S_w + C} + \frac{\sigma_w\cdot S_w\cdot n_e}{\sigma_w\cdot S_w + C}$$

The growth of surface density s on a surface of a liner is limited by distributed pumping C and is defined by the expression:

$$s(t) = s_0 + \frac{1}{A_w}\cdot\int_{t=0}^{t}((\eta(t)+\chi(t)-\kappa(t))\cdot\dot{\Gamma} - C\cdot n(t))\cdot dt\,.$$

The expression for gas density inside the liner can also be written in other form:

$$n(t) = \frac{(\eta(t)+\chi(t)-\kappa(t))\cdot\dot{\Gamma}}{C} + \frac{A_w}{C}\cdot\frac{ds}{dt}.$$

In the equilibrium state when condition $A_w\cdot\frac{ds}{dt}=0$ is satisfied, κ and χ become constant:

$$n = \frac{(\eta+\chi-\kappa)\cdot\dot{\Gamma}}{C}$$

Meanwhile in the equilibrium state

$$\eta_i \geq \kappa_{i\to j+k} \text{ and } \eta_i \geq \chi_j(s_i),$$

hence there is upper limit for the i-th gas density

$$n_i \leq \frac{(\eta_i + \sum_{j\neq i}\eta_j)\cdot\dot{\Gamma}}{C_i},$$

where η_j is photodesorption yield of gases which could produce i-th gas due to cracking.

For example, the gas density for H_2 and CO could be estimated for the equilibrium state as:

$$n_{H_2} \leq \frac{(\eta_{H_2}+\eta_{CH_4})\cdot\dot{\Gamma}}{C_{H_2}},$$

$$n_{CO} \leq \frac{(\eta_{CO}+\eta_{CO_2})\cdot\dot{\Gamma}}{C_{CO}}.$$

3. Experimentally defined parameters.

The following parameters are experimentally determined:

1. For H_2, CH_4, CO and CO_2:
   - The primary photodesorption coefficient η as a function of accumulated photons of at photon critical energy E_c = 284 eV and E_c = 50 eV:
     $$\eta=\eta_0\cdot(\Gamma_0/\Gamma)^{0.33},$$
     here Γ_0 is a accumulated photons corresponding to η_0. [6-8,10]

2. Only for H_2:
   - The sticking probabilities σ_w are: $\sigma_w(E_c$=284 eV) ≈ 0.1 and $\sigma_w(E_c$=50 eV) ≈ 0.5. [7,15]

- The mean molecular speed is $v \approx 8 \cdot 10^4$ cm/sec at the critical photon energy of E_c=284 eV. [9]

3. The photodesorption yields η'_r of all cryosorbed gases H_2, CH_4, CO and CO_2 are found to increase with increasing surface coverage and to reach a saturation value [11–13].
   - This value is about 0.55 molecules/photon for H_2 at $3 \cdot 10^{15}$ molecules/cm^2.
   - For CH_4, CO and CO_2 saturation values reached at surface coverages of three orders of magnitude: at 10^{19} molecules/cm^2. The saturated values are about 0.45 molecules/photon for CO_2 and 0.4 for CH_4 while the corresponding final value for CO is about 0.04 molecules/photon. For the three gases studied, the average removal coefficient shows a very similar behaviour, first increasing with surface coverage but reaching a constant, maximum value for large surface coverage above about 10^{19} molecules/cm^2. For surface coverages below 10^{16} molecules/cm^2, the removal coefficients are so small that they could not be distinguished from the desorption of the bare substrate without pre-condensed gas.
   - Desorption processes of cryosorbed CO_2 and CH_4 molecules involves mostly cracking of these molecules.
   - There was found no dependency of the studied desorption-removal process on temperature 5.5K to 20K for CH_4, 5.5K to 15K for CO and 5.5K to 68K for CO_2.

4. Conclusion

This study allows one to predict the dominating vacuum processes in a vacuum chamber with cryosorbing walls under synchrotron radiation, to describe these processes using experimentally defined parameters and to estimate the gas density under different conditions.

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