

Estimate of Gas Desorption in the NLC Damping Ring *

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1 Introduction

In this note the gas desorption yield in the NLC damping ring is estimated, in particular, its dependence on the slot height of the antechamber. The antechamber is designed to absorb 99.8% of the photon energy from synchrotron radiation. However, a significant fraction of (low energetic) photons, about 7%, will be radiated at angles large enough to hit the vacuum chamber. If the energy of these photons is sufficiently high, they can produce photoelectrons on the chamber wall. Photoelectrons are known to be the main contributors to desorption by synchrotron radiation [2].

2 Analytical Estimate

The gas load due to photodesorption can be expressed in the form (using SI units) [1]:

$$Q_{ges} = 24.2EI\eta \left[\frac{\text{Torrl}}{\text{s}} \right] \quad (1)$$

where E is the beam energy, I the beam current, and the desorption yield η equals the number of desorbed molecules per radiated photon. The desorption yield depends on the vacuum-chamber material, material preparation, exposure to radiation, photon angle of incidence, and photon energy. It is, therefore, often considered as an 'effective engineering value' [1]. Our objective in this note is to calculate the desorption yield η as a function of the antechamber gap height.

The angular and energy distribution of synchrotron radiation is given by the well known formula [3]

$$\frac{d^2N}{d\omega d\Omega} = \frac{1}{3\pi^2} \alpha \omega \left(\frac{\rho}{c} \right)^2 \left(\frac{1}{\gamma^2} + \theta^2 \right) \left[K_{\frac{2}{3}}^2(\xi) + \frac{\theta^2}{\frac{1}{\gamma^2} + \theta^2} K_{\frac{1}{3}}^2(\xi) \right] \quad (2)$$

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where

$$\xi \equiv \frac{\omega \rho}{3c} \left(\frac{1}{\gamma^2} + \theta^2 \right)^{\frac{3}{2}} \quad (3)$$

N is the number of photons, ω the angular frequency, Ω the space angle, α the fine structure constant: and $K_{\frac{2}{3}}, K_{\frac{1}{3}}$ denote modified Bessel functions.

The NLC damping ring operates at a beam energy of 2 GeV and has an aluminum vacuum chamber. The bending magnets are about 70 cm long. Their bending radius p is 4.4 m, the bend angle $\alpha_B = 0.1571$ radian. If a photon is emitted at a sufficiently large angle against the horizontal plane, it will hit the vacuum chamber. The minimum angle θ_{min} for this to occur depends on the slot half height w and also on the location of the emission

$$\theta_{min}(\alpha) = \begin{cases} w/\sqrt{2\rho r} & \text{for } \alpha > \alpha_B/2 \\ w/(\frac{r}{\sin\alpha} + p \tan \frac{\alpha}{2}) & \text{for } 0.0037 < \alpha < \alpha_B/2 \\ w/4 & \text{for } \alpha < 0.0037 \end{cases} \quad (4)$$

where α denotes the position along the bend in radian, measured backwards from the bend exit, and r is the beam pipe radius. The three different expressions refer to the three cases that the radiation hits the chamber inside the same bend, in the downstream straight section or in the following bend. Figure 1 shows the variation of θ_{min} along the bend for three different slot half heights w .

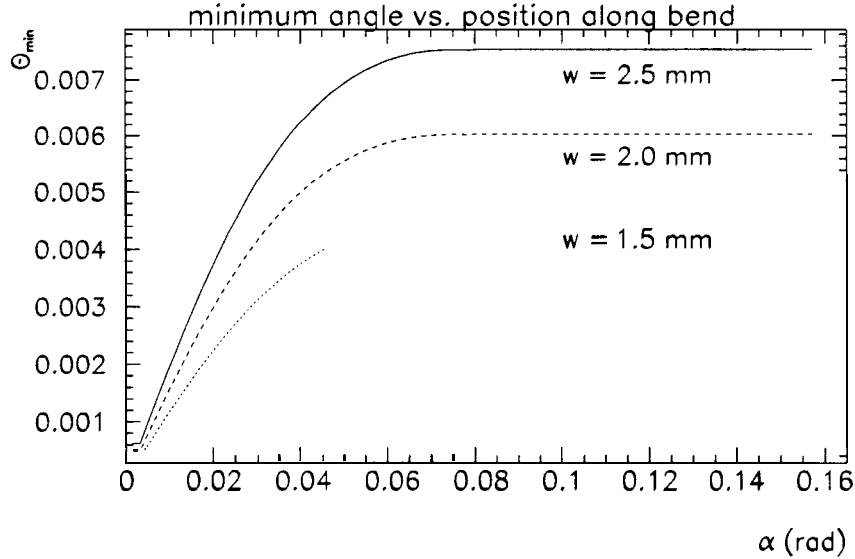


Figure 1: Minimum vertical emission angle to hit vacuum chamber as a function of position along the bend (in radian) for three different absorber-slot half heights w .

The total number of photons radiated per radian and per electron is given by [4]

$$N_{\gamma,tot} = \frac{5}{2\sqrt{3}} \gamma \alpha \approx 42 \quad (5)$$

The number of photons emitted per radian at an angle larger than θ_{min} is obtained by numerical integration of Eq. (2), i.e.

$$N_{\gamma}(\theta > \theta_{min}) = 2 \int_0^{\infty} d\omega \int_{\theta_{min}}^{\pi/2} \frac{d^2 N}{d\omega d\Omega} \quad (6)$$

The number of photons hitting the inside of the vacuum chamber per radian and electron is displayed in Fig. 2 as a function of the minimum angle θ_{min} . Note the strong sensitivity to the minimum angle,

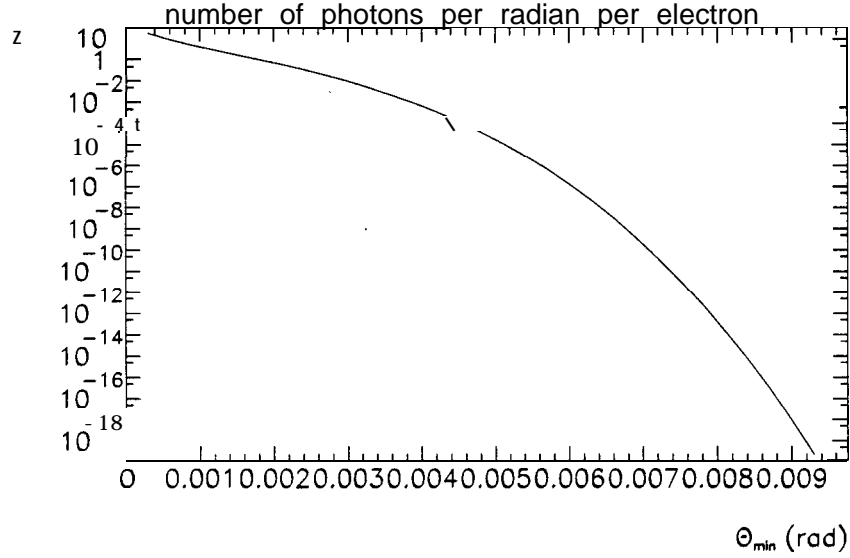


Figure 2: Number of photons hitting the vacuum chamber per electron and radian as a function of minimum emission angle θ_{min} .

which in conjunction with Fig. 1 suggests that the main contribution to gas desorption is due to the small fraction of photons hitting the vacuum chamber in the next bend magnet.

It is generally believed and supported by experiments [2, 5, 6] that the dominant part of gas desorption is due to photoelectrons. We assume the following expression for the photoemission yield η_e [6, 7]

$$\eta_e(E_{\gamma}) \approx \begin{cases} \frac{E_{\gamma}-4\text{eV}}{200\text{eV}} & \text{for } 4 \text{ eV} < E_{\gamma} < 20 \text{ eV} \\ 0.08 \left(\frac{E_{\gamma}}{20\text{eV}}\right)^{-0.59} & \text{for } E_{\gamma} > 20 \text{ eV} \end{cases} \quad (7)$$

where 4 eV is the work function for aluminum. The function $\eta_e(E_{\gamma})$ is illustrated in Fig. 3. In our approximation, the photoemission rises from zero at 4 eV to 8% at 20 eV. It then decreases linearly on a log-log scale and reaches 8×10^{-4} at 50 keV.

If one folds the photoemission yield into the energy integration, one obtains the number of photoelectrons generated per electron and radian. This is illustrated in Fig. 4.

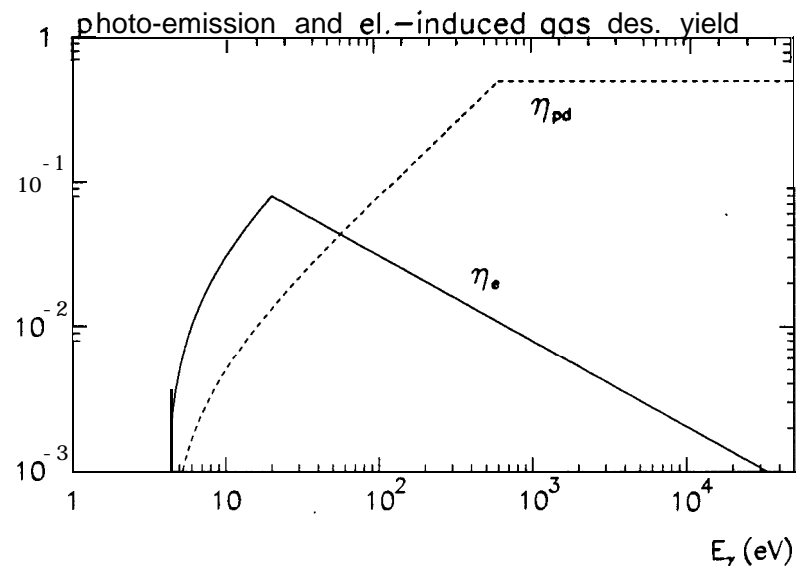


Figure 3: Approximated yields for photoemission and for electron-induced gas desorption as a function of photon energy E_γ ($E_e \approx E_\gamma - 4$ eV).

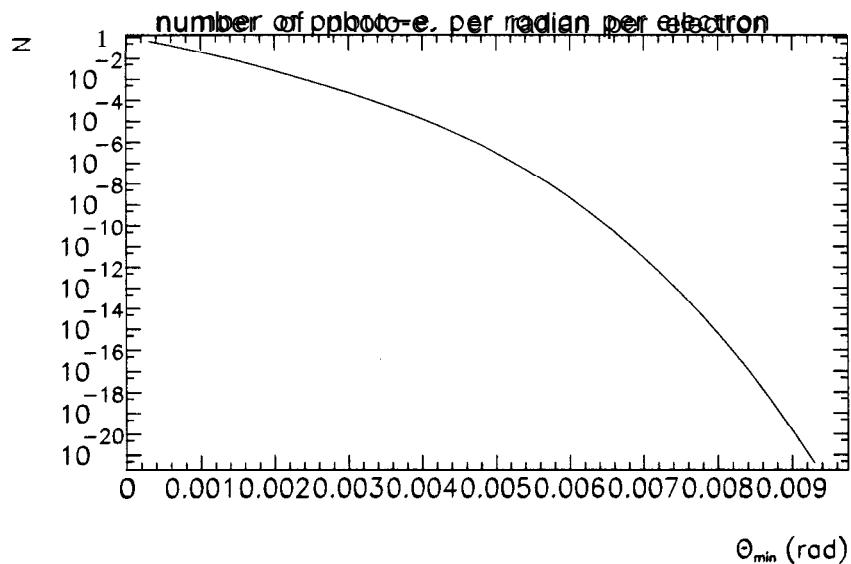


Figure 4: Number of photoelectrons per electron and radian as a function of minimum emission angle θ_{min} .

Finally, the measured electron-induced gas-desorption yield η_{pd} from aluminum [8, 9, 2] may be parametrized as

$$\eta_{pd}(E_\gamma) \approx 0.5 \times \begin{cases} \frac{E_\gamma - 4\text{eV}}{600\text{eV}} & \text{for } E_e < 600 \text{ eV} \\ 1 & \text{for } E_e > 600 \text{ eV} \end{cases} \quad (8)$$

where $E_e \approx E_\gamma - 4 \text{ eV}$ is the electron energy. The yield η_{pd} assumed is also depicted in Fig. 3. The number of molecules desorbed per electron and radian is now estimated from

$$\eta(\theta > \theta_{min}) = 2 \int_0^\infty d\omega \int_{\theta_{min}}^{\pi/2} \frac{d^2 N}{d\omega d\Omega} \eta_e(\hbar\omega) \eta_{pd}(\hbar\omega) \quad (9)$$

where \hbar denotes Planck's constant divided by 2π .

In Figure 5 the number of desorbed molecules per radian and its dependence on the minimum emission angle are depicted.

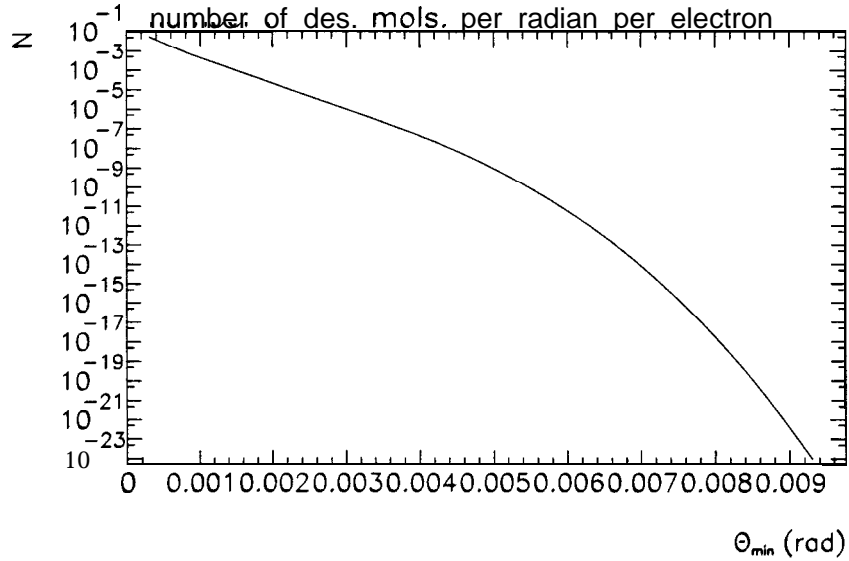


Figure 5: Number of desorbed molecules per electron and radian as a function of minimum emission angle θ_{min} .

An estimate of the effective (initial) desorption yield for the NLC damping ring is obtained by averaging the expression (9), i.e. the minimum angle θ_{min} , over a bending magnet (see Fig. 1 and Eq. (4)). The result is shown in Fig. 6. The absolute value for zero slot height is consistent with published data for photodesorption without prior exposure, see e.g. [10]. Since the coefficient η decreases strongly with the accumulated photon dose: its absolute value may be of less interest than its dependence on the slot half height w .

In the present damping-ring design the slot half height is 2.5 mm. Accounting for chamber misalignments and orbit distortions of $\pm 500 \mu\text{m}$ and for an rms vertical beam size of $400 \mu\text{m}$, the

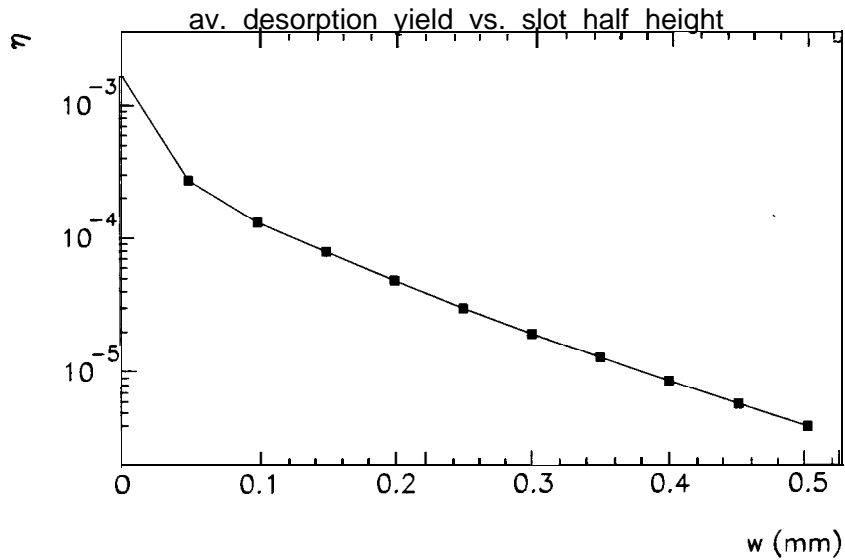


Figure 6: Estimated initial desorption yield in the NLC damping ring as a function of absorber-slot half height.

effective slot half height is about 1.5 mm. Figure 6 suggests that in order to further reduce the desorption by an order of magnitude the slot half height has to be increased by almost a factor of 2, to 4.5 mm.

Acknowledgements

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