Ions produced by a beam on the residual gas induce desorption from the beam pipe wall and may lead to a runaway pressure build up. The main mechanism of ion production is usually inelastic collisions of the beam particles. It may not be true for PEP-II where the combination of high energy and high beam current leads to MWs of the total power $P_0$ in synchrotron radiation. The photoeffect on the residual gas may produce more ions than produced in the inelastic collisions due to a much larger cross-section of the photoeffect $\sigma^+$ at low photon energies $h\omega$ where the number of photons $dP(\omega)/h\omega$ is maximum.

The total cross-section $\sigma_1 = (1 + \Delta)\sigma_e$, where $\sigma_e$ is the cross-section of the inelastic collision and correction $\Delta$, which is the ratio of number of ions produced by photoeffect to the number of ions produced in inelastic collisions, can be estimated as

$$\Delta = \frac{N^+}{N^e} = 0.84\alpha\gamma \sqrt{\frac{\hbar}{\rho}} \int \frac{d\omega}{\omega} \left(\frac{\omega}{\omega_c}\right)^{1/3} \frac{\sigma^+(\omega)}{\sigma^e}.$$  

(1)

Here $\omega_c$ is the critical frequency of the synchrotron radiation, and $\alpha = 1/137$.

The cross-section of the photoeffect on a K-shell electron of a hydrogen-like atom with the ionization potential $Z$ is well known. To describe the low-energy photoeffect we scale it according to the Thomas-Fermi model, replacing well known. To describe the low-energy photoeffect we scale it according to the Thomas-Fermi model, replacing $Z$ by $Z_{\text{TH}}$.

$$\sigma^+ = \frac{Z^2}{Z_{\text{TH}}^2} \left(\frac{Z_{\text{TH}}/I_0}{h\omega}\right)^4 \exp\left[-4|\nu\arccot\nu - 1|\right] \left[\frac{I_0}{h\omega_c}\right]^{1/3} \left(\frac{a_0^2}{\sigma^e}\right).$$  

(2)

where $Z = Z^2 I_0$, $\nu = (h\omega/I - 1)^{1/2}$, $I_0 = 13.6$ eV, and $a_0 = 0.5 \times 10^{-8}$ cm are parameters of a hydrogen atom. Numerical calculations give

$$\frac{\int d\omega}{\omega} \left(\frac{\omega}{\omega_c}\right)^{1/3} \frac{\sigma^+(\omega)}{\sigma^e} = 0.094Z^{7/9} \left[\frac{I_0}{h\omega_c}\right]^{1/3} \left(\frac{a_0^2}{\sigma^e}\right).$$  

(3)

For the parameters of the PEP-II HER and $Z = 28$, $\Delta = 1.35$, and the total cross-section is larger than the inelastic cross-section by the factor 2.35.

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*Pressure Stability under a Pump Failure*

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The pressure $P(z)$ along the pipe in the straight sections is found to be

$$P(z) = \frac{q_{sr} L}{4W \psi^2} \left[-1 + \frac{\cos(\Omega z - \psi)}{\cos \psi - (2W/S)\psi \sin \psi}\right],$$  

(4)

where $q_{sr}$ is the ion induced outgasing rate per unit length induced by synchrotron radiation, $q_i = \eta \sigma_e (I/e)$ is the outgasing induced by the ions produced in collisions with the residual gas, $I$ is the average beam current, $\psi = \Omega L/2$, $\Omega = \sqrt{q_i/LW}$, $L$ is the pump separation, $S$ is the pumping speed in (l/sec), and $W$ is the pipe conductance in (l/sec). The desorption coefficient $\eta$, the number of outgased molecules per ion, depends on the ion mass, energy, material and treatment of the wall, and can change in the wide range from $\eta \approx 0.01$ to $\eta \approx 10$.

Equation 4 shows that $P(z)$ goes to infinity if $\psi \tan \psi = S/2W$, defining the threshold current $I_{th}$ at which pressure instability takes place. For the parameters: $\sigma^e = 2 \times 10^{-18}$ cm$^2$, $W = 24.8$ l/sec, $S = 68$ l/sec, and $\eta I_{th} = 10.47$ A. Figure 1 shows the pressure profile for $\eta = 1$ and the current in the range from 1 A to 9 A.

Consider now a situation when a pump at $z = 0$ fails doubling the pumping distance. The pressure profile in this case for the range $-L < z < L$ is

$$P(z) = \frac{q_{sr} L}{4W \psi^2} \left[-1 + \frac{\cos(\Omega z - \psi) \cos \psi}{\cos 2\psi \cos \psi - (2W/S)\psi \sin 3\psi}\right],$$  

(5)

giving the maximum pressure at $z = 0$.

The solution describes substantial increase of the pressure at $z = 0$ (by a factor $\approx 4$) compared to Eq. (4) and predicts the runaway situation at the current defined by

$$\frac{\psi}{\cos 2\psi} \frac{\sin 3\psi}{\cos \psi} = \frac{S}{W}.$$  

(6)

The lowest root of this equation defines the threshold current

$$\frac{L}{W} \eta I_{th} \sigma_e = 6.4 \psi^2,$$  

(7)

where $L$ is in meters, $W$ is in l/sec, $I_{th}$ in amperes, and $\sigma_e$ is in units $10^{-18}$ cm$^2$. This function is shown in Fig. 2 for the normal case (low curve) and with pump failure (upper curve). The right-hand side goes to a maximum value of 3.9 at large $S/W$ giving $\eta I_{th} = 4.96$ A for the
Figure 1. Pressure profile between pumps separated by 7 m for the beam current from 1 A to 9 A. The ion induced threshold current is $I_{th} = 10.469$ A for $W = 24.8$ l/sec, and $S = 68$ l/sec.

The conductance calculated from local conductances (M. Sullivan, private communication) is $W = 841$ l/sec and $S = 4001$ l/sec for the interaction region $\pm 2.45m$ from IP. That gives quite high $\eta I_{th} = 27.4A$.

Figure 2. Parameter in the LHS of Eq. (7) versus $S/W$.

The threshold current is given by the pumping speed $s$ of the distributed ion pumps for the HER arcs: $\eta I_{th} \sigma_c = 1.6s$ where $s$ is in l/sec, $\sigma_c$ is in $10^{-18}$ cm$^2$, and $I_{th}$ in A is very high for $s = 120$ l/m/sec.

The situation is less obvious for the wiggler vacuum chamber (under design).

The estimate shows that PEP-II should not have a problem with a pressure instability at nominal pumping speed provided that $\eta$ remains small, $\eta < 1$. 