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Pressure Stability under a Pump Failure*

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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 σ^γ at low photon energies $h\omega$ where the number of photons $dP(\omega)/h\omega$ is maximum.

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

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

Here ω_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 charge Z is well known. To describe the low-energy photoeffect we scale it according to the Thomas-Fermi model, replacing parameters of a hydrogen-like atom by the parameters of an atom with the ionization potential I_0 . That gives

$$\sigma^\gamma = 0.23Z \frac{a_0^2}{Z^{2/3}} \left(\frac{Z^{4/3}I_0}{h\omega}\right)^4 \frac{\exp\{-4[\nu \arccot \nu - 1]\}}{1 - \exp\{-2\pi\nu\}}, \quad (2)$$

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

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

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

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

where q_{sr} is the ion induced outgassing rate per unit length in (torr l/m/sec) induced by synchrotron radiation, $q_i = \eta\sigma_t(I/e)$ is the outgassing 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 η , 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 $\eta \simeq 0.01$ to $\eta \simeq 10$.

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: $\sigma^E = 2 \times 10^{-18}$ cm², $W = 24.8$ 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

$$P(z) = \frac{q_{sr}L}{4W} \frac{1}{\psi^2} \left[-1 + \frac{\cos(\Omega z) \cos \psi}{\cos 2\psi \cos \psi - \frac{W}{S}\psi \sin 3\psi} \right], \quad (5)$$

giving the maximum pressure at $z = 0$.

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

$$\psi \frac{\sin 3\psi}{\cos 2\psi \cos \psi} = \frac{S}{W}. \quad (6)$$

The lowest root of this equation defines the threshold current

$$\frac{L}{W} \eta I_{th} \sigma_e = 6.4\psi^2, \quad (7)$$

where L is in meters, W is in l/sec, I_{th} in amperes, and σ_e is in units 10^{-18} cm². 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

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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.

pipe $r = 5$ cm, $L = 7$ m, and $\sigma_c = 210^{-18}$ cm². The threshold current is reduced from 10.47 A to 4.75 A for the parameters used above.

The conductance calculated from local conductances (M. Sullivan, private communication) is $W = 84$ l/s and $S = 400$ l/s for the interaction region ± 2.45 m from IP. That gives quite high $\eta I_{th} = 27.4$ A.

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: $\eta I_{th} \sigma_c = 1.6 * s$ where s is in l/sec, σ_c is in 10^{-18} cm², 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 η remains small, $\eta < 1$.

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