Interrupted Pumpdown of a Vacuum System*

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Abstract

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The pressure rise due to a surface outgassing process following a real pump closure has been analyzed and found under a physically reasonable parameter selection to occur very quickly yet result in a very slight actual pressure change. Real leaks thus should be able to be able to be distinguished from surface outgassing processes by this technique.

1. Introduction

During the pumpdown of a vacuum system it is not unusual to temporarily valve off the real pump and observe the pressure rise with respect to time to try to estimate the degree to which:

- i) The system is clean, i.e., the wall outgassing rate is reasonable.
- ii) Real leaks are present.
- iii) Virtual outgassing sources are present.
- iv) The system including the pumps and gauges is behaving properly.

The object of this study will be to determine the extent to which the above can be determined by an observation of the time dependence of the pressure rise following a pump closure.

2. Model and Analysis

For definiteness consider the following procedure:

- i) Pump the system following an atmospheric exposure for t_0 seconds.
- ii) Close S, the real pump at t_0 seconds.
- iii) Allow the system to leak up for a time t_1 . Measure $\left. \frac{dp}{dt} \right|_{t_0}$ and $p(t_1)$.

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Consider a vacuum system of volume $V(\ell)$ pumped on by a real pump of pumping speed $S(\ell/s)$. Conserving the molecular flux into and out of the system:

$$V \, dp/dt = f_w - pS - pS_w \quad (1)$$

where p is the system pressure (torr), S_w is the pumping speed of the wall (ℓ/s) and f_w is the rate at which molecules are strictly desorbing from the wall (torr. ℓ/s). Similarly conserving flux into and out of the wall:

$$\frac{dn_w}{dt} = pS_w - f_w \quad (2)$$

where n_w is the number of molecules on the wall at time t (torr. ℓ). Further assume that the rate at which molecules strictly desorb from the wall is proportional to the number on the wall; i.e.

$$f_w = n_w/\tau_w \quad (3)$$

where τ_w is the constant of proportionality, the soujourn time.

The pumpdown of the vacuum after an atmospheric exposure is governed by Equations (1), (2), and (3). Using the model constraints described in Reference 1 the largest the pressure can be t_0 seconds after the start of the pumpdown is given by¹:

$$P_m = 1.15 \times 10^{-5} A/St_0 \quad (\text{torr}) \quad (4)$$

where A is the wall area in cm^2 . The actual pressure at t_0 , $p(t_0)$ is less than or equal to P_m . Now if at time t_0 the real pumping speed is changed by S liters/second it is shown in Reference 2 that the change in dp/dt at t_0 is given by:

$$\left. \frac{dp}{dt} \right|_{t_0+} - \left. \frac{dp}{dt} \right|_{t_0-} = P(t_0)/\tau \quad (5)$$

where $\tau = V/S$. Using the fact that $P(t_0) \leq P_m$ and neglecting $\left. \frac{dp}{dt} \right|_{t_0-}$ it is found that:

$$\left. \frac{dp}{dt} \right|_{t_0^+} \leq 1.2 \times 10^{-5} \frac{A}{Vt_0} \quad \{\text{torr/second}\} \quad (6)$$

which remarkably enough is independent of the pumping speed of the pump which was pumping on the vessel for the previous t_0 seconds.

Let us now determine the pressure itself during the rate of rise measurement. Consider that the volume was pumped for the previous t_0 seconds by an S liter/second pump and that at $t=0$ the pump is turned off leaving $n_w(t_0)$ molecules on the wall in a particular desorption state (sojourn time τ_w), and $n_g(t_0)$ molecules in the gas phase.

The differential equation describing the pressure as a function of time is easily found to be

$$\frac{d^2 p}{dt^2} + \frac{1}{\tau_e} \frac{dp}{dt} = 0 \quad (7)$$

with

$$\frac{1}{\tau_e} = \frac{1}{\tau_w} + \frac{1}{V/S_w}$$

The solution of Equation 7 for $P(t)$ proceeds in a straightforward manner using as the boundary conditions:

$$P(t_{0-}) = P(t_{0+})$$

together with Equation 5. For $t < t_0$ $P(t)$ has been found in Reference (1) to be:

$$P(t) = \frac{n_w(0)}{\tau_w S(1+k)} \left(1 + \phi(\delta) \right) * \left\{ e^{-f} + \frac{e^{-g}}{k} \right\} : (t < t_0) \quad (8)$$

where $k = S_w/S$, $\delta = \tau/\tau_w$, $\tau = V/S$

$$f = \frac{t}{\tau_w(1+k)} * (1 + \phi(\delta))$$

$$g = \frac{t(1+k)}{\tau_s} * (1 + \phi(\delta))$$

Similarly for $t > t_0$, $P(t)$ can be written:

$$P(t) = \frac{\tau_e n_w(0)}{\tau \tau_w S(1+k)} e^{-t_0/(\tau_w(1+k))} * \left\{ 1 + \frac{\tau}{\tau_e} e^{-t/\tau_e} \right\} \quad (9)$$

for $t > t_0$

where $n_w(0)$ is the number of molecules adsorbed onto the wall at the start of the pumpdown. It is noted that $t=0$ in Equation (9) corresponds to $t=t_0$ of Equation (8).

The time during which the pressure rises for $t > t_0$ is seen from Equation (9) to be given by τ_e which, considering $\tau \ll \tau_w * k$, may be written:

$$\tau_e \cong \tau/k$$

which is both very small and in fact for large τ_w does not depend on τ_w .

For very long times after the real pump has been turned off it may be shown that

$$P(\infty) \cong \frac{(1+k)}{k} P(t_0)$$

Thus for large k and reasonably long sojourn times the pressure change after closing the real pump is expected to both occur quite rapidly and be of very small magnitude.

Figures 1 and 2 give computer plots of Equations (8) and (9) for various model parameters. Seen in these figures is both the slight change in pressure upon turning off the real pump and the rapid approach to equilibrium illustrated more clearly in Figure 2.

3. Discussion

If a real leak is present of magnitude Q torr.liters/second then upon closing the real pump the pressure rise (primarily N_2) will be linear with respect to time and is given by:

$$P = \frac{Q}{V} * t \text{ (torr)}$$

This behavior is qualitatively different from the pressure rise due to a surface outgassing process (primarily H_2O) and thus the two processes are distinguishable by the closure of the real pump.

It may be worthwhile to emphasize that at the present time the pressure rise due to outgassing of virtual leaks³ after the real pump closure has not been analyzed, is thought to be quite complex, and thus unknown even in a qualitative sense.

The above discussion may be stated in a slightly different way: In the absence of virtual leaks the process (real leaks or surface phase outgassing) responsible for the pressure rise after the closure of a real pump should be identifiable. In the presence of virtual leaks the pressure rise after the real pump closure is not known.

References

1. D. Edwards, Jr., J. Vac. Sci. Technol. 14, 606 (1977).
2. D. Edwards, Jr., Vacuum 27, 631 (1977).
3. D. Edwards, Jr., Vacuum 29, 169 (1979).

Figure Captions

1. The pressure plotted as a function of time following the closure of a real pump during a pumpdown from atmosphere.
2. An enlarged view of the region around $t = t_0$ for one of the plots in Figure 1. Seen is the very rapid attainment of equilibrium after the pump closure as discussed in the text.

Fig. 1

Fig. 2