*LIGO Laboratory / LIGO Scientific Collaboration*

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# Trapped volume venting guidelines

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Detector Technical Review Board

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## Introduction

Assemblies for LIGO vacuum service must be designed with attention to venting potential trapped volumes. Numerous methods are available,[i] including drilled or slotted fasteners, thread inserts, split washers, and milled or etched surface channels. The question of minimum effective vent channel size often arises. This note offers perspective in terms of equivalent leak rate or decay time. In general, a channel 100 microns in effective diameter provides substantial margin for most LIGO applications, assuming it is kept clear.

In some cases (e.g., welded structures) vent channels are also relied upon for solvent flushing or inspection. Such channels should normally be much larger to suit those functions.

## Leak speed and gas flux

Consider the generic trapped internal volume in Figure 1.

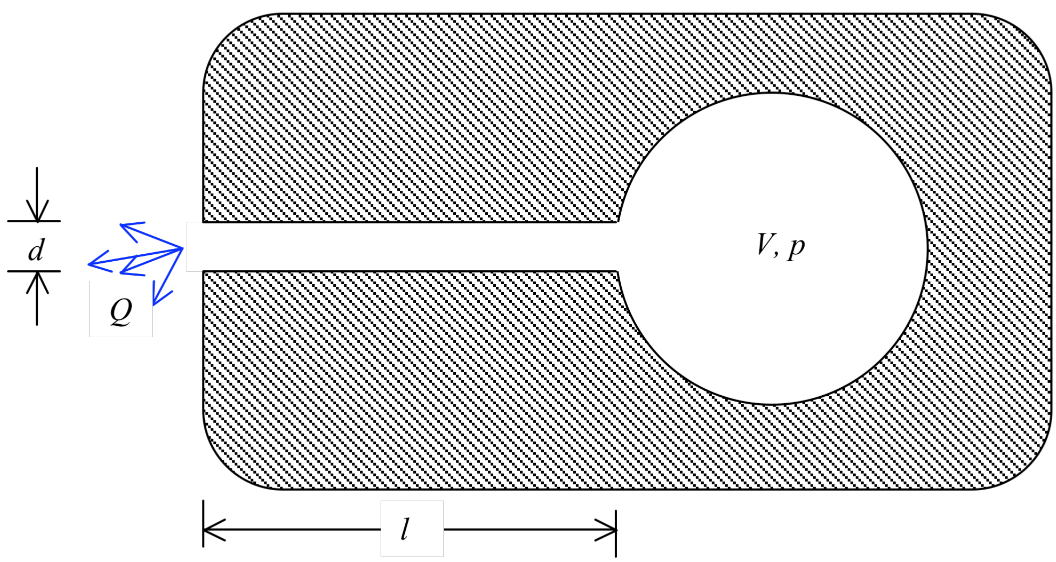


**Figure 1: A trapped volume *V* at internal pressure *p* is bled by vent channel of diameter *d* and length *l.***

For a narrow vent channel $d << l$, the channel conductance $F$ in the molecular flow regime is given by[ii]

$$
\begin{aligned}
F &= const.\times\frac{d^3}{l\sqrt{m}}\\
&\approx 1.2\times10^4\,\frac{\mathrm{cm}^3}{\mathrm{s}}\cdot\left(\frac{d}{1\ \mathrm{cm}}\right)^3\cdot\left(\frac{1\ \mathrm{cm}}{l}\right)\cdot\left(\frac{28\mathrm{AMU}}{m}\right)^{1/2}\\
&\approx 1.2\times10^{-8}\,\frac{\mathrm{liter}}{\mathrm{sec}}\cdot\left(\frac{d}{10\ \mu\mathrm{m}}\right)^3\cdot\left(\frac{1\ \mathrm{cm}}{l}\right)\cdot\left(\frac{28\mathrm{AMU}}{m}\right)^{1/2}
\end{aligned}
$$

where $m$ is the molecular weight of the gas (at ambient temperature of 20° C). The last form should be considered against the nominal pump speed for relevant LIGO volumes, of order $10^4$ liter/second for air.

Presuming the trapped volume $V$ is initially at atmospheric pressure, and neglecting the effect of viscous flow, the initial gas flux is roughly

$$
\begin{aligned}
Q &= pF\\
&\approx 10^{-5}\,\frac{\mathrm{torr}\cdot\mathrm{liter}}{\mathrm{sec}}\cdot\left(\frac{p}{760\ \mathrm{torr}}\right)\cdot\left(\frac{d}{10\ \mu\mathrm{m}}\right)^3\cdot\left(\frac{1\ \mathrm{cm}}{l}\right)\cdot\left(\frac{28\mathrm{AMU}}{m}\right)^{1/2}.
\end{aligned}
$$

This is comparable to the steady state hydrogen load in the largest LIGO volumes after years under vacuum, and well below initial air and water loads days or weeks after an extended vent.

## Depletion time constant

The virtual leak decays exponentially by depletion. Even if initially dominant, it will eventually be overtaken by outgassing. For example, water outgassing falls roughly as $t^{-1}$ for diffusion out of Flourel™ seals.

Strict operability could thus tolerate a virtual leak that merely dissipated faster than water vapor, on the order of days-weeks for typical vent cycles. However, an early air signature may confound QA on feedthroughs, ports and flanges parted during the vent. To prevent confusion, a time constant comparable to or shorter than the time to hard vacuum (order 1 day or less) is desirable.

Presuming a trapped volume $V \sim 1\ \mathrm{cm}^3$ (e.g., the blind end of a tapped 1/4" hole), the e-folding time constant $\tau$ will be

$$
\begin{aligned}
\tau &= \frac{V}{F}\\
&\approx 24\ \mathrm{hours}\cdot\left(\frac{V}{1\ \mathrm{cm}^3}\right)\cdot\left(\frac{10\ \mu\mathrm{m}}{d}\right)^3\cdot\left(\frac{l}{1\ \mathrm{cm}}\right)\cdot\left(\frac{m}{28\mathrm{AMU}}\right)^{1/2}.
\end{aligned}
$$

## Bad welds

An interesting special case is that of a long thin channel open at one end. This might arise from a double-sided butt weld (e.g., the LIGO beam tube spiral weld) with inadequate weld penetration. We can approximately substitute $V \approx \pi d^2 l/4$ to obtain

$$\tau' \approx 10 \text{ minutes} \cdot \left(\frac{10\ \mu\text{m}}{d}\right) \cdot \left(\frac{l}{100\text{ cm}}\right)^2 \cdot \left(\frac{m}{28\text{AMU}}\right)^{1/2}.$$

Our nominal practice of single-sided full penetration welding, or skip welding on the back side, should effectively eliminate this mode in any case.

## Threads

The tightest internal threads used in LIGO assemblies are fit class 2B. For a ¼-20 fastener size the corresponding pitch diameter is .0036" oversize (on 0.218" nominal), leaving a .0009" x .028" rectangular cross-section gap on the untensioned thread face.

Neglecting root and tip clearances, which will usually be comparable, this helical gap has an effective cross-section equivalent to that of a 140 μm diameter circular channel[1]. At an engagement of two bolt diameters (10 turns) the channel is 18 cm long. One cc of blind volume at the bottom of this hole thus vents along the unmodified helix with a time constant of order 10 minutes (provided the bolt head is not permitted to form a seal).

However, shedding, flaking or galling during assembly can generate debris that might plug the clearance. Some explicit venting therefore seems prudent unless fastener compatibility is tightly controlled.

## Conclusion

A 10 μm diameter by 1 cm long vent channel bleeding trapped atmosphere could initially give air flux just comparable to steady-state LIGO outgassing, and barely violate typical component leak specifications. At the same time, a trapped volume of order 1cc will dissipate rapidly enough through such a channel to clearly distinguish it from a true external leak. It will also certainly be invisible by the time a LIGO chamber reaches service.

Where feasible, I suggest conservatively providing vent channels 100 μm (.004") or greater in effective diameter. We should also try to limit dead volumes to a few cc or less. This will give time constants of minutes or less, aid visual inspection, and reduce the possibility of accidental blockage by burrs or metal deformation. However, one should keep in mind that in an emergency, a deep scratch with a scribe ought to be enough.

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[i] Moore, Davis, and Coplan, *Building Scientific Apparatus,* 3rd ed. Westview Press (2002).
[ii] O'Hanlon, *A User's Guide to Vacuum Technology,* 3rd ed. Wiley Interscience (2003).

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[1] Strictly the conductance of such a rectangular channel is less than a circular channel of equivalent area, but we are looking at order-of-magnitude effects.