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PVD Processes: Leaks & Leak Detection

Real Leaks

Real leaks connect the vacuum volume to the outside ambient through a low-conductance gas-flow path. Real leaks may be a result of:

- Porosity through the vacuum chamber wall material
- Porosity or cracks in areas of permanent joining, such as welds
- Poor breakable seals resulting from scratches or contamination on sealing surfaces, inadequate compression or shearing of gaskets, or defects in the sealing gaskets
- Leaks in water cooling lines within the vacuum system
- Cracks in feedthrough insulators

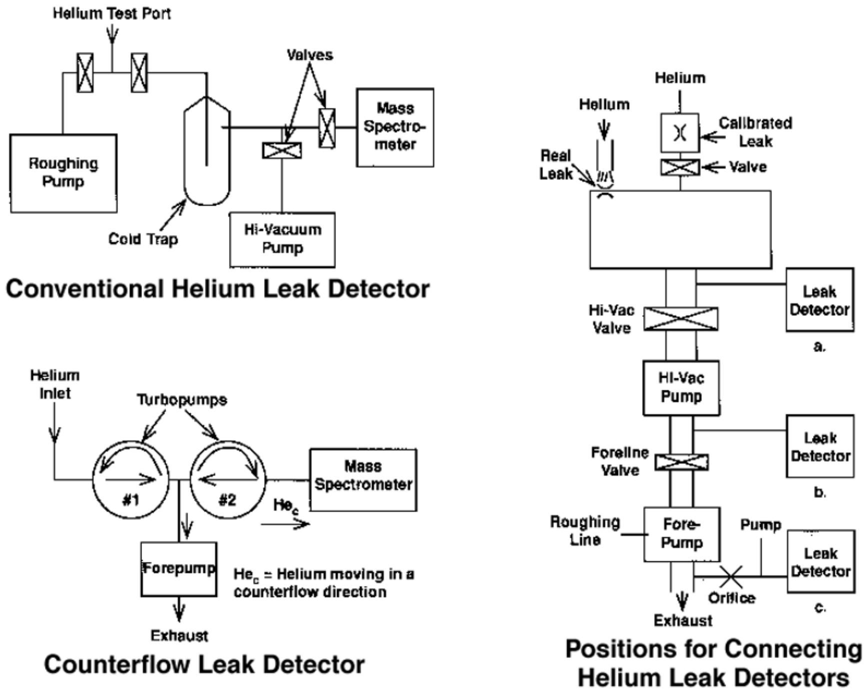
Real leaks can be minimized by proper vacuum engineering, fabrication, assembly and care during operation.

Virtual Leaks

Virtual leaks are internal volumes with small conductances to the main vacuum volume. Virtual leaks may be a result of:

- Surfaces in intimate contact
- Trapped volumes (*e.g.*, unvented bolts in blind, tapped bolt holes)
- Pores in weld joints and construction materials
- Porosity in coating buildup on vacuum surfaces during repeated processing.

Virtual leaks can be minimized by proper design and construction of vacuum chambers and fixtures, and tooling in the chamber. Virtual leaks resulting from porous coating material buildup can be minimized by periodic cleaning of removable and non-removable surfaces.



Configurations for conventional and counterflow leak detectors, and methods of attaching a leak detector to a vacuum system.

Outgassing

Outgassing is when the gas or vapor originates from inside a bulk material and must diffuse through the material before it is released at the surface. Permeation is when the gas or vapor originates from outside the vacuum system and diffuses through solid materials before it reaches the surface in contact with the vacuum. Often, virtual leaks are difficult to differentiate from outgassing and permeation.

Leak Detection

Determining whether a leak is real or virtual can take appreciable detective work. One technique is to backfill the vacuum chamber with an uncommon gas, such as neon. On subsequent pump-down, if the neon peak in a residual gas analyzer (RGA) spectrum disappears rapidly, the leak is probably a real leak. If it decreases slowly, however, it probably indicates the presence of virtual leaks. Gases originating from virtual leaks and outgassing will decrease over time, but gases from permeation will stay constant with time. Heating will hasten the evacuation of virtual leaks and the outgassing of materials, and will increase the permeation rate.

The existence of leaks in a system can be detected by system behavior, as well as leak detection techniques. System behavior that can indicate real or virtual leaks include a behavior different from that under previous conditions (*i.e.*, baseline condition of the system when it is working well). The baseline condition can include:

- Time to reach a specified pressure (base pressure)
- Leak-up (leak-back) rate through a given pressure range when the vacuum pumping system has been valved off
- Change in residual gas composition as determined by an RGA

The leak rate is the amount of gas passing through a leak in a period of time and depends on the pressure differential, as well as the size and geometry of the leak path and, to some extent, the temperature and gas species. Leak rates are usually given in units of pressure-volume/time, such as Torr-liters/sec or STD cm^3/sec.

Leak detection and leak locating techniques include:

- Detection of an indicator gas by means of its mass—usually helium
- Detection of the radioactivity from an indicator gas—usually Kr^{85}, a 12-keV beta emitter

Under optimum conditions, Kr^{85} leak detectors can detect leaks on the order of 10^{-13} Torr-liters/sec. This is often done by "bombing" the vacuum chamber by putting it in a high-pressure chamber filled with krypton gas continaing about five percent Kr^{85}. The Kr^{85} that enters the vacuum chamber is detected using a Geiger-Müller counter. High-pressure bombing can also force krypton into pores and leaks, and then the escaping Kr^{85} can be detected when the pressure is decreased. This type of leak detection is used to ensure hermetic sealing of an enclosed package where there is no access to the interior of the package.

The most common leak-detection technique uses a helium mass spectrometer, where helium is applied to areas on the outside of the vacuum vessel while it is under vacuum, and helium is detected using a mass spectrometer. Usually, the helium mass spectrometer uses a magnetic sector analyzer, rather than the quadrapole analyzer typically used on RGAs. Under optimum conditions, helium leak detectors can detect leaks on the order of 10^{-11} Torr-liters/sec, although a sensitivity of 10^{-9} Torr/liters/sec is more commonly attained. The observed leak rate can be quantified by calibration of the leak detector with a standard leak. An RGA can be used for helium leak detection, but it is often more expensive and not as rugged as the helium leak detector.

Leak detectors can be used in a partial-flow configuration, where only a portion of the helium goes through the leak detector. It is important that the total pressure and helium partial pressure in the mass spectrometer be kept low if high sensitivity is to be attained. Typically, the pressure in the spectrometer should be below 10^{-4} Torr. The figure shows a conventional helium leak detector. The liquid nitrogen cold trap is used to prevent contamination—such as water vapor or oil vapor—from entering the mass spectrometer.

High pressure and contamination in the mass spectrometer can be minimized by using a "counterflow" configuration, as shown in the figure. In a compression-type vacuum pump, such as a turbomolecular pump, the ratio of the partial pressures of a gas at the pump outlet to that at the inlet, under zero gas flow conditions, is the compression ratio of the pump for that gas. The compression ratios differ for different gases, with the compression ratio for helium being rather low in a turbopump. This means that if helium is present at the outlet of the turbopump, then helium will appear at the inlet of the pump in an amount prescribed by the compression ratio.

In the counterflow leak detector shown in the figure, turbopump #1 pumps helium from the inlet into the outlet manifold of turbopump #2, and out the forepump. The helium at the outlet of turbopump #2 causes a helium partial pressure to appear in the mass spectrometer, where it is detected. Turbopump #2 maintains a good vacuum in the mass spectrometer and prevents heavier gases and vapors from contaminating the mass spectrometer.

The figure shows several methods of attaching the helium leak detector to the vacuum chamber. In position (a), when the hi-vac valve is open, the leak detector is operating in a partial-flow mode. If the hi-vac valve is closed, the leak detector is operating in a full-flow mode. In position (b), the leak detector is operating in a partial-flow mode and may have to have an orifice in the manifold to allow the mass spectrometer to operate in a good vacuum. In position (c), the leak detector is operating in a partial-flow mode and will probably have to have auxiliary pumping to allow a good vacuum in the mass spectrometer. Position (a) is the best position, and the vacuum plumbing should be designed to allow this configuration.

Because helium is lighter than air, it should be applied to local areas from the top down. The speed of movement of the helium probe is important, because small leaks can be missed by a fast-moving probe. A coaxial helium probe with a small-bore helium-dispensing tube, surrounded by a vacuum tube, can be used to help pinpoint the location of a leak.

Determining the location of a leak after assembly may be difficult—particularly if there are a lot of leaks, or if potential leak areas are hidden behind components on the surface of the vacuum chamber. To minimize leaks in the assembled system, joints and subsystem components should be helium-leak-checked as much as possible before assembly. As a final leak check, the system can be covered with a plastic bag that is then filled with helium (bag check) to determine the cumulative effect of all leaks. As a baseline for system behavior, a new system should be "bag-checked" (also called a hood test) to determine its total leak rate. Later, it can be bag-checked to see if leaks have developed. A good production system might have a total leak rate of 10^{-7} Torr-liters/sec as-fabricated, as a result of several small leaks.

Some of the procedures used in the operation of the vacuum processing system are designed to prevent the system from developing real leaks with use. These include:

- Wiping sealing surfaces and O-rings before the chamber is closed to prevent debris from scratching the sealing surfaces or cutting the O-ring
- Protecting the sealing surfaces during loading, unloading, cleaning and maintenance
- Installing and removing O-rings without damaging the O-ring surface or the sealing surface
- Torquing flange-bolts in a pattern such that the flanges are not warped
- Protecting feed-throughs from damage

Fixing leaks may be easy—or may be difficult and expensive. When using large, mild steel vacuum chambers, the chamber is often painted to seal porosity in the metal. There are special low-vapor pressure sealants and adhesives made for sealing vacuum leaks. If a sealing surface is scratched or dented, the surface may be repaired by local polishing to a 32-µin. or better finish, with the polishing texture in a direction parallel to the axis of the O-ring. If the scratch or dent is deep, or the flange is warped, it may be necessary to refinish that surface by machining. This can be very expensive. In some cases, an adequate seal can be made between warped surfaces by using an inflatable elastomer "balloon gasket." If the knife-edge of a metal shear seal, such as a CF-flange, has been damaged, the shear gasket may be replaced by a metal "C-gasket," in some cases. P&SF

Conversion: 1.0 Torr-liter/sec = 133 Pa-liter/sec = 1.316 STD cm^3/sec = 3.535×10^{19} molecules/sec (at 0 °C)

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