Leak Checking Large Vacuum Chambers

Technical Overview

Vacuum Technologies

Introduction

Understanding the pump-down characteristics of a large vacuum vessel is critical for determining whether the vacuum system is behaving normally, or if it has a source of outgassing or developed a real leak.

Finding leaks on large vacuum chambers using a helium leak detector is fast, efficient, and cost-effective. The proper selection of a leak detector, the connection of the detector to the vacuum system, and the appropriate use of helium tracer gas are fundamental to a successful leak test.

Typically, large vacuum chambers use a high vacuum pump (turbo or diffusion) backed by a roots-type blower and mechanical pump. This method provides the fastest response and cleanup.

While this Technical Overview describes large systems that are pumped in this manner, the methods described are applicable to vacuum chambers of all sizes.

Vacuum System Behavior

The behavior of most large vacuum systems evolves over time. Chambers used for production processes will almost inevitably develop leaks that can affect product quality, and damage internal components. Leaks can develop in multiple locations including; valves, feedthroughs, door seals, and so forth. Large leaks in a vacuum system are usually obvious: the chamber will not pump down as expected, or it will bottom out at a pressure well above its typical base pressure. Small leaks, however, are more difficult to troubleshoot, and often go undetected, as the pumping system can easily overcome the gas load of the leak. Even if the vacuum gauges still read appropriate levels, the leak may show up as a contamination inside the chamber.

Figure 1. Leak detection of large volume vacuum chambers.

Pump-down curves

One of the most valuable tools for understanding the behavior of a large vacuum system is the historical performance of the vacuum system. Seasoned technicians keep meticulous data on pump-down curves, and can quickly identify when the system is not performing as expected. They do this by comparing present performance with a previous cycle made when the system was in a good working order. Evaluation of the pressure versus time curve, such as the example shown in Figure 2, can indicate the presence of a leak.

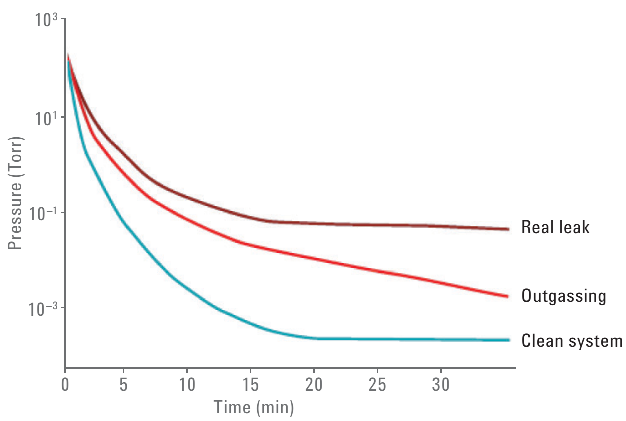

Figure 2. Typical vacuum pump-down curves.

If the vacuum level is slow to reach the original base pressure, then outgassing is suspected. Outgassing is additional gas load caused either by trapped volumes of gas inside the chamber, or a source of contamination (that is, inadequate chamber cleanliness). This gas load is released slowly, and results in a pump-down curve similar to the one shown in red in Figure 2.

Real leaks, gas entering the chamber from the outside, will cause the pump-down to stall at a higher pressure than normal. These real leaks result in a pump-down curve resembling the one shown in brown in Figure 2.

Rate of rise (bleed-up) test

Another valuable technique in leak detection is the use of rate of rise or bleed-up test. To perform a bleed-up test, a valve between the vacuum pump and the chamber must be closed, allowing the chamber pressure to rise or bleed-up. After a short stabilization time (approximately 15 minutes), the rate of rise of the vacuum system is calculated (dividing the increase in pressure by the elapsed time) and graphed to produce a rate of rise plot, as shown in Figure 3.

In industry, rate of rise and bleed-up are normally expressed in µm/hr. For typical applications, a rate of rise exceeding 10 µm/hr requires investigation and resolution of the problem.

A rate of rise that stays constant (over multiple measurements) is indicative of a real leak. See System A in Figure 3, and notice how the rate of rise stays relatively constant over time, and the system pressure continues to rise over time. In contrast, a rate of rise that decreases as the pressure increases is indicative of a virtual or outgassing leak. See System B in Figure 3, and notice how the rate of rise decreases over time, and the increase in system pressure slows over time.

Observing the pump-down cycle and performing a rate of rise test may not lead to immediate detection of the problem. This is because the overall cleanliness of the vacuum system can influence these tests. In addition, pump-down and rate of rise tests will not locate leaks, but will only indicate the cumulative effect of all leaks (real and virtual) combined.

If a real leak is indicated or suspected, the use of a helium leak detector is usually the next step.

Helium Leak Detection

Basic principle of helium leak detection

Helium leak detection works by introducing helium to one side of a vacuum chamber wall, and using a highly sensitive mass spectrometer (tuned specifically to admit, ionize, and detect helium) to measure minute traces of the gas passing through the vessel wall.

Helium is used as a tracer gas for several reasons. Primarily, it is present in only small amounts in ambient air, resulting in low background. Second, helium is fast-moving, improving the time for the detector to respond to a leak. Further benefits of helium include its availability, and the fact that it is nontoxic, nonflammable, and completely inert.

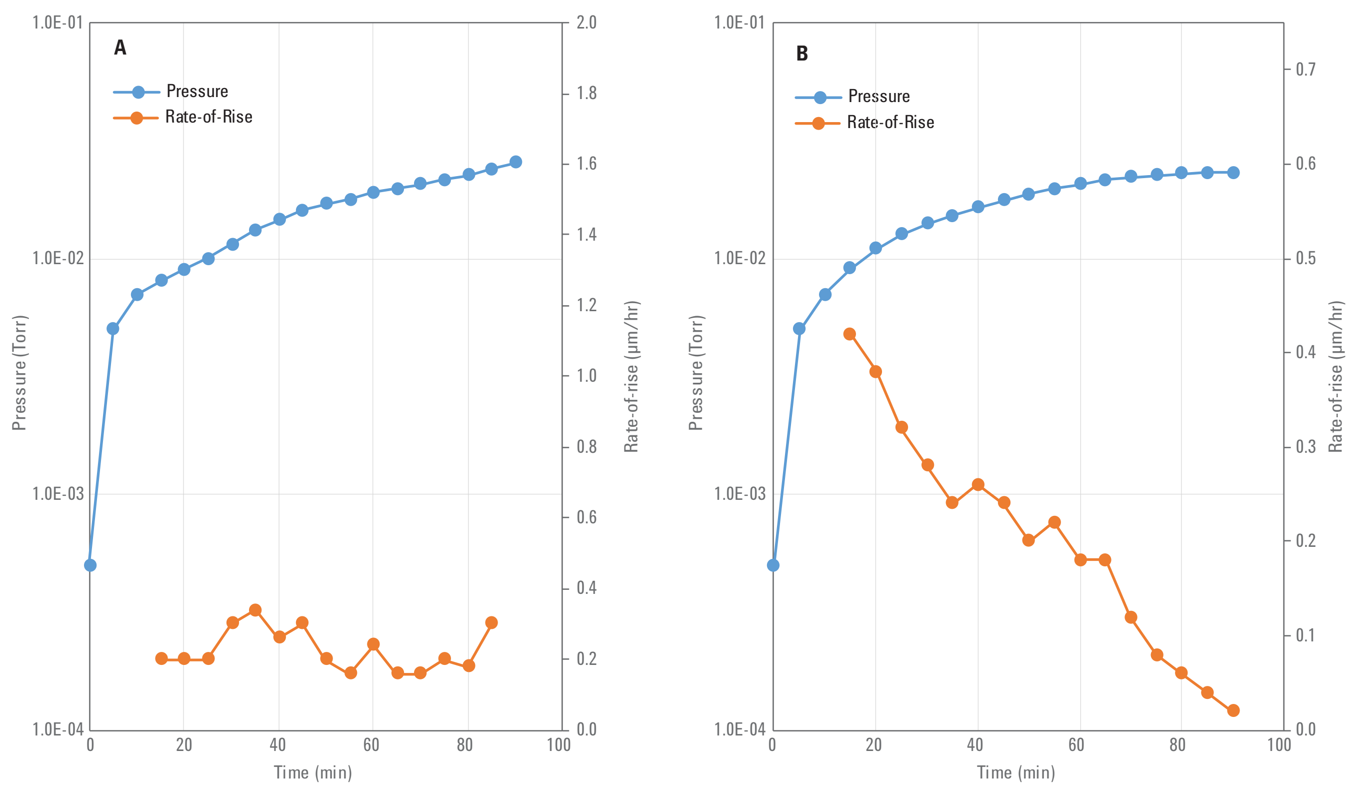

Figure 3. Comparing rate-of-rise plots for a real leak (System A) and outgassing (System B).

Benefits of helium leak detection

Helium leak detection is the ideal solution to determine the vacuum tightness of a large vacuum chamber. Major advantages of helium leak detection technology include:

- The ability to quickly pinpoint the location and relative magnitude of the leak. Therefore, less time is spent making repairs.
- Outgassing issues do not affect the method. Therefore, tests can be performed regardless of chamber condition.
- It can be performed quickly, and can be a routine operation at the start of each production run, saving time and reducing scrap.

Important parameters

When discussing helium leak detection of large vacuum chambers, three interrelated parameters must be considered: appearance time, cleanup time, and sensitivity.

Appearance time

The time for a helium leak detector to register a significant change in the helium background is known as the appearance time. In contrast, the term response time in leak detection is reserved for an accumulation factor: the time for the detector to register 63 % of the maximum signal observed when a leak is exposed to a steady flow of helium gas.

Appearance time is related to the background level of helium in the system. It is typically defined as the time for the leak detector to display a signal that is two (or sometimes three) standard deviations of the background helium signal above that background: referred to as 2 Sigma or 3 Sigma.

A helium leak detector's appearance time is strongly influenced by the location of the helium leak detector in the system, as well as being related to the size of the chamber.

Cleanup time

Once a leak is found, the helium that leaked into the system must be pumped away to continue testing. Cleanup time depends on the helium pumping speed of the vacuum pumps on the chamber.

Sensitivity

Sensitivity, defined as the ability of the helium leak detector to identify the smallest possible vacuum leak, can be a challenge when leak checking large vacuum systems. Maximum sensitivity is achieved when 100 % of the helium entering the vessel (though the leak) is delivered to the leak detector. This can be achieved in practical terms by replacing the chamber's forepumps (blower and RVP in Figure 5) with the leak detector. However, connecting the leak detector directly to the vacuum chamber (Position C in Figure 5) is impractical since the instrument does not have a pumping system capable of evacuating the volume in a reasonable time.

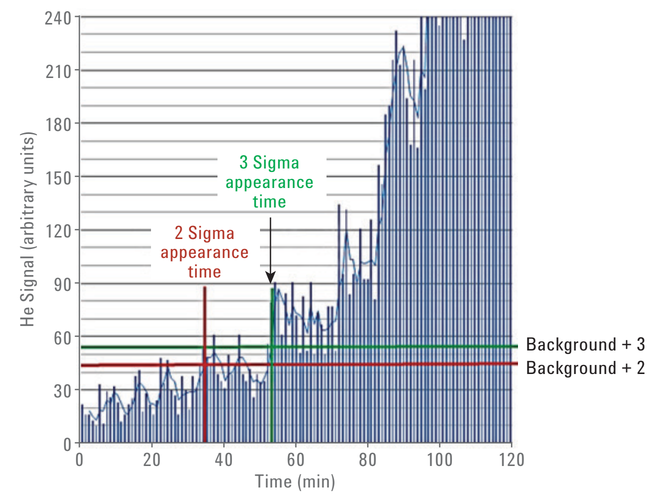

Figure 4. Helium appearance time (2 Sigma and 3 Sigma).

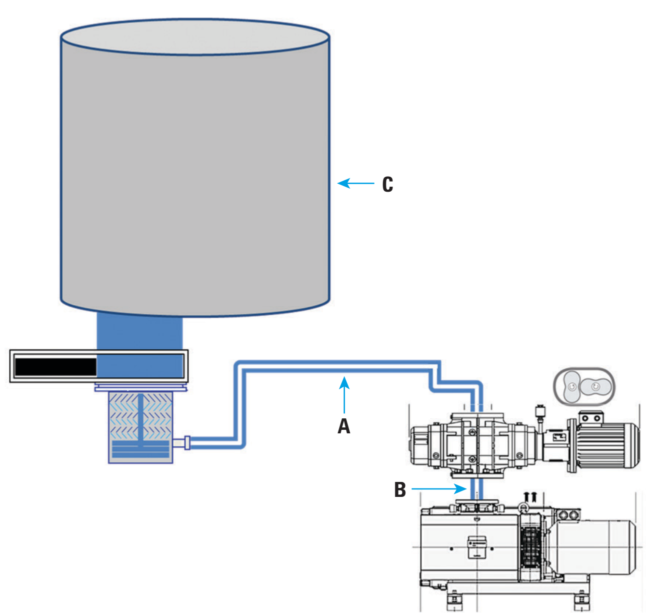

Figure 5. Leak detector positioning on a vacuum chamber with high vacuum pump and blower.

Positioning the leak detector

The ideal location for leak detection of the chamber shown in Figure 5 is position A. This location takes full advantage of the chamber's high vacuum pump to reduce both appearance time and cleanup. Helium background and oil backstreaming are also reduced, since the blower provides an extra barrier against both helium and oil-mist escaping the rotary vane pump inlet.

Sensitivity is slightly reduced (versus Figure 6), but this can be offset by trapping helium around the leak location (bagging) or adjusting the leak detector to compensate. Some leak detectors offer split flow adjustment to enhance detection of small leaks even when the leak detector is coupled to a system with large pumps (as in Figure 5).

Alternate configurations: Installing the leak detector at position B would result in poor stability, and high helium background. Once a leak is found, helium can be trapped in the mechanical pump, creating a high background signal that impedes further testing. Cleanup time also suffers in this configuration because of the poor helium pumping speed of the chamber's mechanical pump. Finally, connections close to the mechanical pump can also be dirty due to oil backstreaming from the pump, and can contaminate the leak detector. As described earlier, position C (connecting the leak detector directly to the vacuum chamber) will result in a very long pump down time and a very slow helium cleanup.

Maximum sensitivity: Chambers that need to reach very low vacuum pressures (that is, need to have the smallest leaks identified and repaired) require the leak detector to operate in maximum sensitivity mode. This mode can be achieved by mounting the leak detector at position A and taking advantage of the detector's split flow detection capability. Alternatively, maximum sensitivity mode can be achieved by replacing the chamber's forepumps (blower and rotary vane pump) with the leak detector, as shown in Figure 6.

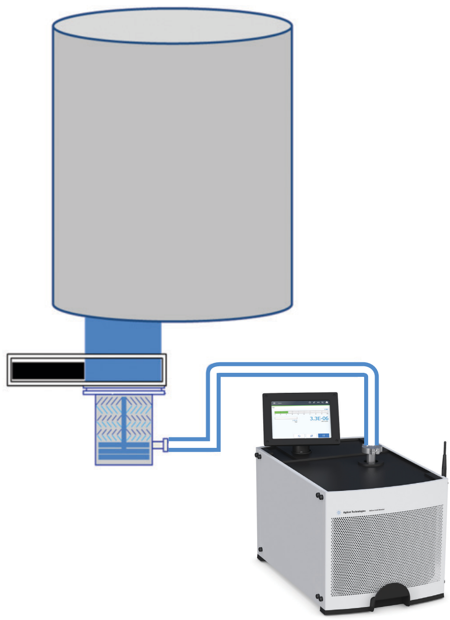

Figure 6. Positioning of the leak detector for maximum sensitivity.

Conclusions

Agilent HLD leak detectors are the ideal choice for detecting leaks in large volume vacuum systems. HLD leak detectors are simple to use, with onboard touch screen operation, and an optional wireless handheld remote. The flexibility of the HLD, particularly its use of split flow detection to enhance sensitivity, offers the perfect solution for leak checking large vacuum chambers.

Using a leak detector with remote control can improve efficiency and reduce operator time, provided they allow full control of the leak detector at significant distance from the unit. When performing leak testing on large volume vacuum systems, the operator may be spraying helium a considerable distance from the leak detector. They would therefore be unable to observe the instrument response directly. The HLD wireless handheld remote control allows leak testing up to 100 m from the base unit. Thus, where leak checking large systems previously required two technicians, the HLD wireless remote allows a single operator to complete this task.

The three key parameters of helium leak detection (appearance time, cleanup, and sensitivity) are interrelated, and how the leak detector is connected to a large vacuum chamber greatly impacts these parameters. The ideal location for the leak detector is between the chamber's high vacuum pump and blower (shown as position A in Figure 5). In this position, appearance time and cleanup are optimized. To compensate for slightly reduced sensitivity, a leak detector using split flow detection is recommended. Agilent HLD leak detectors offer a split flow adjustment, allowing small leaks to be identified even when the leak detector is coupled to a system with large pumps. In practice, the exceptional sensitivity of Agilent HLD leak detectors allows for rapid, accurate detection of even the smallest chamber leaks regardless of the size of the vacuum vessel being tested.

www.agilent.com/en/products/
vacuum-technologies/leak-detection

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