Tip of the month/No. 17

Virtual Leaks

Question: What is a virtual leak?

Answer: According to DIN EN 1330-8 a virtual leak is „an apparent (not real) leak, caused by slow release of sorbed or occluded gases from surfaces or bulk of material or from volumes partially trapped within the system".

Background: The key component of the above definition is the **slow release of gases.** This clearly identifies the effect of virtual leaks as gas sources that slow down a pumping process or significantly prolong the time to reach the desired base pressure. The technical term „occluded" cited in the above-mentioned standard means „trapped" or „enclosed". A good example of a virtual leak is an air-filled cavity in the interior of a vacuum chamber with no connection to the outside, but which has a narrow channel connecting it to the evacuated interior of a vacuum chamber.

The gas flow rate from the virtual leak is determined by the dimensions of the leak channel between the trapped gas reservoir and the free volume of the vacuum chamber. If the channel is very small, the trapped gases are released very slowly due to the high flow resistance of the channel, and the pump-down time for the chamber can be significantly extended. If the vacuum system is repeatedly vented, the gas reservoir can replenish itself over and over again. This effect is repeated every time pumping occurs.

The pump itself does not influence the degassing rate. The leakage rate (in mbar·l/s) from the cavity is in equilibrium with the gas extracted by the pump, i.e. the pumping speed (l/s) multiplied by the actual pressure (mbar).

Enclosed gas volumes may, for instance, occur in joining processes during the production of a vacuum chamber. If, for example, a wall of a vacuum container is to be butt welded onto a bottom plate, inexperienced designers often specify a double fillet weld (see Figure 1). This runs the risk that gas becomes trapped between the two welds. If the welding seam on the vacuum side is not tight, the trapped gas will spread into the interior of the vacuum chamber. This will happen slowly due to the high flow resistance of the small pores between the trapped gas volume and inner volume of the chamber. If, at the same time, the outer welding seal is tight, there is no way to localize the leak using helium leak detection. The welds that are accessible from the atmospheric side are therefore not continuous, but are either interrupted or subsequently spot-drilled.

For the same reason, the CF flanges are provided with a leak detection groove. It can generally be said that a serial connection of seals always poses a risk of virtual leaks. The inner seal is the relevant seal to the vacuum, while an outer seal encloses a cavity and prevents the helium used for leak detection from reaching the relevant seal.

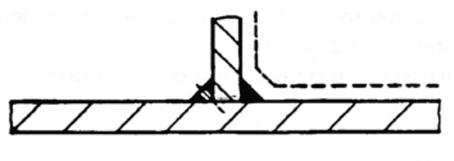

Figure 1: Double fillet weld (Source: Jobst H. Kerspe et al., Vakuumtechnik in der industriellen Praxis, expert-Verlag) [Vacuum technology in industrial practice]. The vacuum side is indicated by the dashed line.

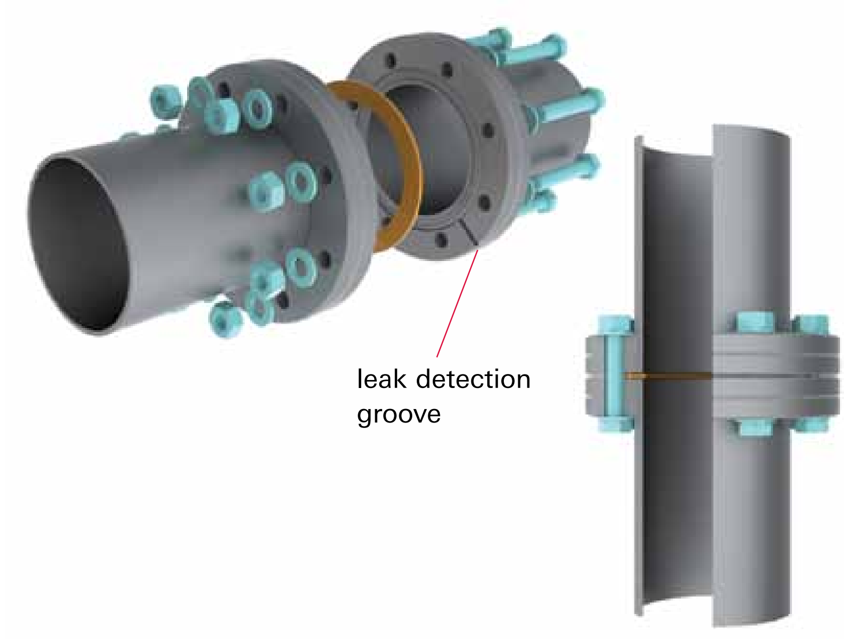

Figure 2: The CF leak detection groove opens the undefined sealed volume between the flange surface and the copper gasket

Previously, we have said that the dimensions of the leak channel determine the degassing rate. A classic example is when gas escapes from a blind hole through the thread of a screw in the wall of a vacuum chamber. A vent hole of blind holes or cannulated screws can be used to accelerate the gas leak from the blind hole. But the presence of a hole weakens the core and reduces the bearing capacity. If geometry permits, a vent hole can be created from the side into the thread runout.

Figure 3: The shaft end of the rotary feedthrough is an internal thread with a side vent hole

Figure 4: Screw with vent hole (Source: Karl Jousten (Publ.) Handbook Vacuum Technology, 11. Edition, Vieweg & Teubner Verlag Wiesbaden, 2013).

If installations are mounted in chambers, threaded sleeves which are already provided with venting grooves can be welded onto the chamber wall, instead of drilling threads into the chamber wall.

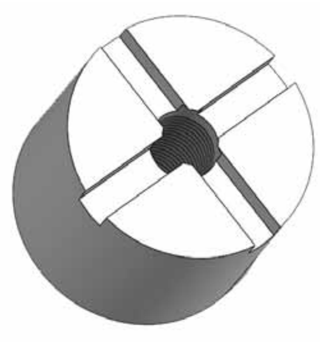

Figure 5: Threaded sleeves with milled venting grooves

Figure 6: Centering rings with outer support ring for ISO-K connections are slotted and allow for ventilation

Occasionally, virtual leaks occur simply due to a gap between two flanges, if the clamping ring is tightened to its maximum and the gasket is squashed.

Double lip seals are often used in chamber seals to minimize the permeation gas flow. But if the inner seal has a leak, it will in turn create a virtual leak. Grooves are the solution for evacuating the dead volume behind the O-ring and a vacuum connection between double O- rings. This allows trapped gases to be pumped out, and helium leak detection to be carried out individually for each of the two seals.

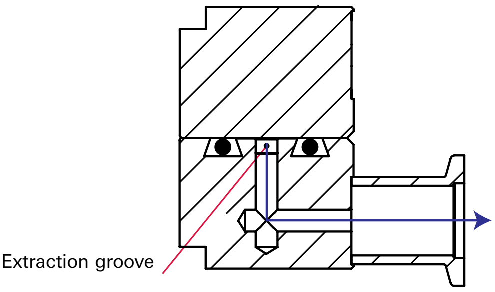

Figure 7: Double O-ring seal with interseal pumping

Until now we have only spoken of gases that are located in enclosed volumes. The above effects of virtual leaks, i.e. extension of the pump-down time and slow attainment of the desired base pressure, become even more pronounced if water vapor is confined in a virtual leak. This can occur, for example, by venting with moist ambient air or water escaping from a cooling water pipe inside the vacuum chamber. After escaping from a virtual leak, water vapor will accumulate at the coldest point in a vacuum chamber and become even more difficult to pump down than the atmospheric gases such as nitrogen, oxygen or argon that adhere less strongly to the surface.

This leads us to a trick that can be used to detect virtual leaks: If the vacuum system is equipped with a mass spectrometer, although a virtual leak cannot be localized by venting with an inert gas, it can however be detected by the increased ion current on the relevant mass. For example, if a chamber with a virtual leak after venting with helium will be evacuated again, the intense signal of 4 u reveals the presence of a virtual leak.

If venting was done with argon, the user can possibly save a vacuum process, in which an inert noble gas does not interfere in contrast with humidity or oxygen. An example of this involves sputtering processes, in which argon is often used as a process gas.

Until now we have dealt with trapped gases. According to the definition mentioned above, gases can also adhere firmly to the surface or be stored within a material. In addition to the cleanliness of the installed parts, the choice of materials affects the outgassing behavior of the overall system.

Sealing materials and equipment used in vacuum technology store light gases, especially hydrogen, water, but also air and solvent residues. Emissions are determined by diffusion through the volume onto the surface. The volume for these materials should be kept small.

Some materials enter into the gas phase themselves. This vapor pressure is highly dependent on temperature. For liquids such as greases, oils or water, it can turn into a dominant gas source even at room temperature. In metals, for example, zinc shows a high vapor pressure; it should therefore be avoided in solid materials as well as in welding wires or in solders.

Aluminum always has a passive oxide layer on the surface. In untreated (native) aluminum, this layer is only a few nanometers thick and completely tight. Through anodizing, this layer can be thickened to several 10 microns and this improves the hardness considerably. However, these anodized layers are very porous and often form a virtual leak. Therefore, anodized layers are often omitted in vacuum systems.

Ceramics are often sintered oxides that reach an effective density of between 80 to 99 percent, depending on the manufacturing process. The disadvantage of possible pores is usually compensated by good bake-out properties.

Metals and glasses are usually tight, but they adsorb gas at the surface. In ultra-high vacuum, this is the dominant gas source if all other virtual and actual leaks have been eliminated.

In summary, one can say that even during the design and construction of a vacuum chamber or the integration of installations, utmost care should be taken to prevent virtual leaks.

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