Pump down curves and their information value

Pfeiffer Vacuum are specialists in vacuum technology. They provide the highest quality testing in order to provide top class products. Here we learn about the importance of the pump down curves and the different materials that can affect them.

Displaying and interpreting processes in different vacuum ranges

Pump down curves are a popular control instrument when designing and operating a vacuum system. Thanks to them, any problems in the system can be derived and the correct pump performance can be assessed.

A pump down curve describes a time-dependent pressure drop in a vacuum system. In a graphical representation, the time is applied to the X-axis and the pressure to the Y-axis. For the known geometry of the vacuum chamber and pumps, a pump down curve can be calculated. Any deviations between the calculated and the measured pump down curve will often provide information about problems in the vacuum system. This also applies to the comparison of curves measured over long-term use with a reference curve.

Pump curves in in the low vacuum range: displaying connections, interpreting, and applying

A reference curve can be measured when the system runs properly and without any problems after startup. Under these conditions, the pressure drop is measured over time during pump down. The measurement can either be taken manually, using a system control, or using the software packages for pressure gauges provided by Pfeiffer Vacuum.

In the example in Figure 1, the calculated pump down curve of a 100-liter chamber is displayed. A Duo 65 rotary vane pump was used as a vacuum pump. This curve serves as the standard for comparison. In Figure 1, it is assumed that the pump is directly connected to the chamber.

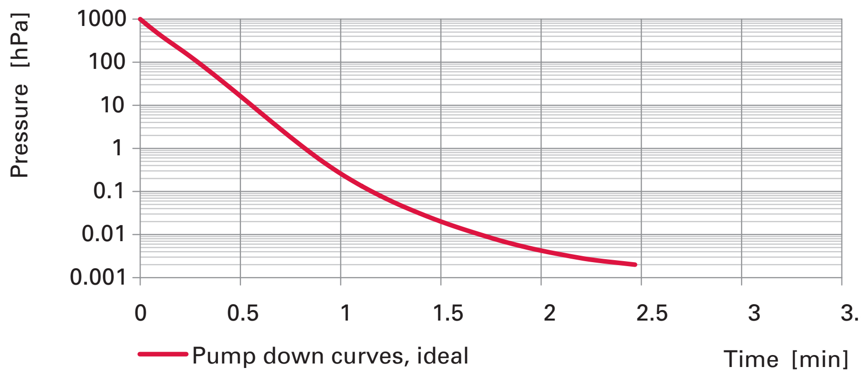

Figure 1: Pump down curve of a 100-liter chamber with a rotary vane pump Duo 65

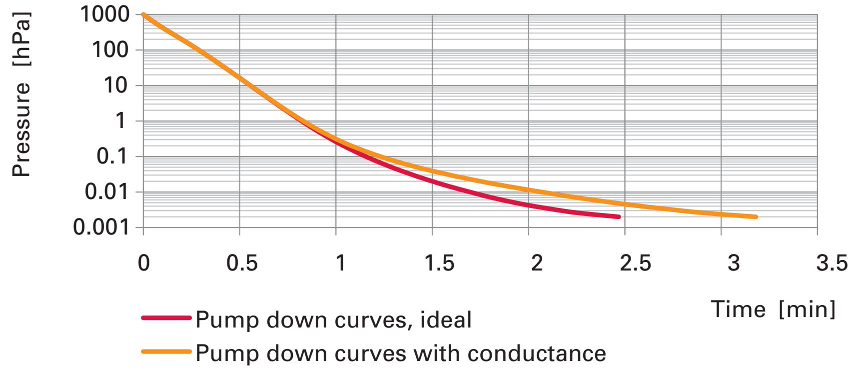

Figure 2: Conductance effect

In Figure 2, the effect of a flexible corrugated hose on the pump down behavior can be seen. It is used as a connection between the chamber and the pump. The tube has a length of 1000 mm and a diameter of 40 mm.

The connecting bellows have almost no effect on pump down time above a pressure of approximately 1 hPa. But if we want to further evacuate the chamber down to 0.01 hPa, the pump down process will

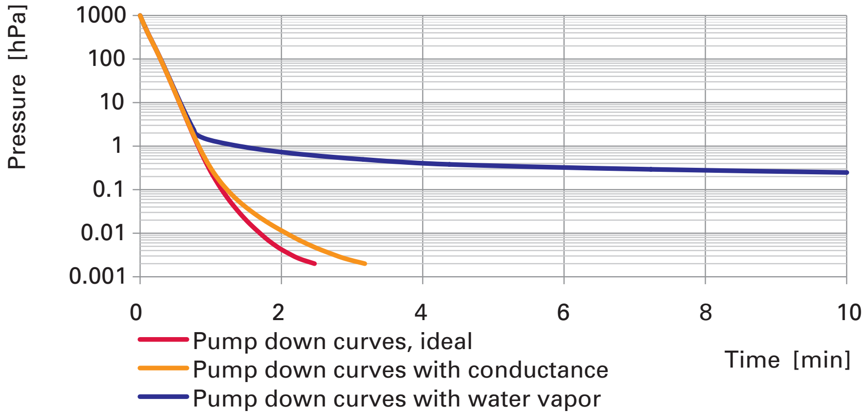

Figure 3: Influence of water on the pump down process

take about 20% longer, solely due to the effect of the bellows. A solution for this is to shorten the connection piece or to increase the piping diameter.

Flow resistance depends linearly on the length, but in the third or fourth power on the diameter. If in doubt, the diameter should be increased as a corrective measure rather than shortening the connection. In this case, the comparison between the two curves shows the influence of the pipe and can help with designing the connection between the chamber and the pump.

Pump down curves display different influences

The operation of the vacuum system can be influenced drastically by different factors:

- **Influence of water**

Figure 3 shows the influence of a small amount of water on the pump down process:

The previously achieved base pressure is missed by more than a factor of 100 and the time scale seems to be almost infinitely extended. This example of a curve has been measured in an existing coating system. Over time, both the parts and the carriers have been coated. Coating of the parts is a well-controlled process in order to achieve a dense layer with high adhesion and tailored tribological properties. However, coating of the carriers is a random process which leads to a coating with a loose, brittle multi-layer structure with low adhesion. The loose, layered structure tends to release particles and form a large surface area. On this surface area, which has built up over time, large amounts of water vapor can now accumulate and these thin absorbent layers cannot be detected with the naked eye. The time required for the pump down has not suddenly become longer but has been slipping over an extended period of time during operation.

The first step of pumping down water vapor from vacuum chambers consists of a slow desorption of the water film adhering to the inner surfaces of the vacuum chamber. This particular surface process is significantly slower than the pump down of a gas or a vapor, which is already in the gaseous phase.

Figure 3 shows the bend of the pump down curve in the range between 10 and 1 hPa, which is typical for a water vapor adsorbed layer on a surface of the vacuum chamber or from installations. This value may change depending on the vapor pressure of the medium or the accessibility of the surface.

- **Influence of alcohol**

If the vacuum system is cleaned with a highly volatile alcohol, such as isopropanol, the alcohol will evaporate quickly. Evaporation takes place more quickly than the pump down and no bend in the pump down curve is observed as in the water entry in Figure 3.

- **Influence of oils or operating fluids**

Oils and operating fluids from backing pumps may indeed have a significant impact on and create a hump in the pump down curve with a lower pressure than in the given example. This also applies to water vapor desorption, which does not come from a free surface but, for example, from a winding.

- **Influence of films for thermal insulation**

Figure 5 shows the effect of using a film for thermal insulation in the interior of the vacuum chamber.

The desorbing medium is actually water vapor, but due to the stronger bond to the

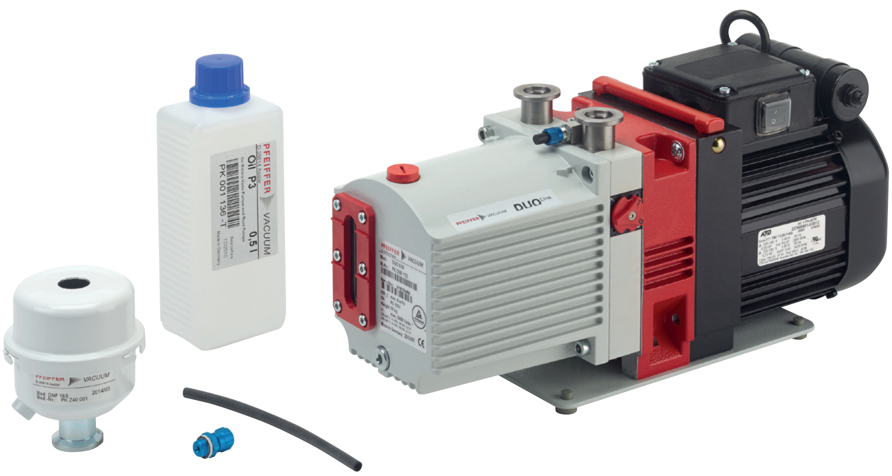

Figure 4: Oil and operating fluids from backing pumps may have a significant impact on pump down curves

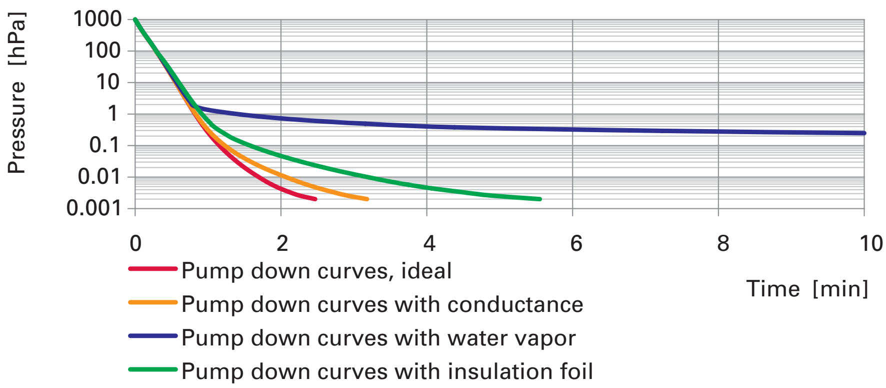

Figure 5: Pump down curve with a 10 cm^2 insulation foil in the vacuum chamber

surface and the slow escape from the foil winding, the water signal only appears at a lower pressure. In the given example, the addition of just 10 cm^2 of foil insulation leads to an extension of the pump down time up to a base pressure of 75%. In addition to insulation foils, cable sheathing or other plastics in the vacuum can display similar effects.

- **Pump down curves in the high vacuum range**

Even if vacuum is defined as empty space, it does not mean that there are no gases at all left in high vacuum systems. Also at low pressures, water vapor can greatly affect the achievable base pressure of a system. Water may outgas from the surfaces of the vacuum chamber. The outgassing rate depends to a great extent on the surface materials, such as metal, glass or plastics. In addition to the material, the quality of the surface can also have a major influence on the outgassing rate.

- **Influence of different materials in the high vacuum range**

As an example, the standard KBH type cubical chamber from Pfeiffer Vacuum is regarded. The medium-sized chamber has an edge length of 500 mm. In cubic geometry, this corresponds to a surface of 15,000 cm^2. On this surface, a supply of gas is adsorbed which is slowly released from the surface. This outgassing takes place much slower than the pumping down of gas that is freely present in the room. Data for the outgassing rate from surfaces can be found in tables attached to vacuum textbooks.

For the chamber material (stainless steel 1.4301 or SS 304), an outgassing rate per unit area of approximately $1.3 \cdot 10^{-9}$ mbar·l·s^{-1}·cm^{-2} is specified. This rather unwieldy unit gives a gas flow in mbar·l·s^{-1} in relation to a surface area in cm^{-2}.

If the value of the outgassing rate per unit area is multiplied by the surface area of our chamber, this results in an outgassing rate of $1.95 \cdot 10^{-5}$ mbar·l·s^{-1}. If we evacuate the chamber with a HiPace 300 type turbopump with a pumping speed of 300 l/s, we theoretically obtain a base pressure of $6.5 \cdot 10^{-8}$ mbar. The data provided in tables are usually measured after a pumping time of one hour. We therefore need an hour to reach the specified pressure. The outgassing rate can be reduced by pumping or baking out the vessel for a prolonged period.

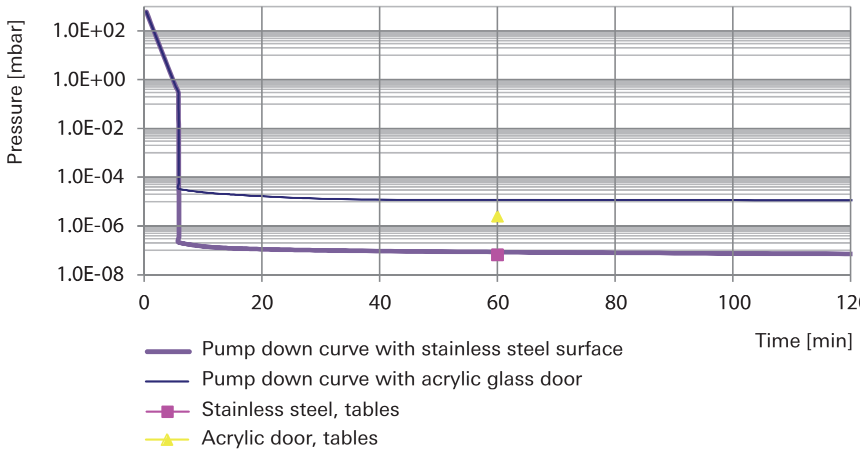

Figure 6: Pump down curve of a vessel with 500 mm edge length; pumping system: backing pump and HiPace 300 turbopump

Differences between stainless steel and acryl

With a stainless steel door, the processes inside the chamber cannot be observed. However, replacing a stainless steel door with a transparent acrylic glass door changes the material and the surface of the door and also affects the desorption gas flow. In tables, the desorption rate per unit area of acrylic glass is given as around $300 \cdot 10^{-9}$ mbar·l·s^{-1}·cm^{-2}.

This means that if we replace 1/6 of the stainless steel surface with the acrylic door, we get a desorption gas flow totaling $7.66 \cdot 10^{-4}$ mbar·l·s^{-1} and thus a base pressure of $2.55 \cdot 10^{-6}$ mbar. Essentially, the observation facility through the transparent door is achieved at the cost of attaining a higher base pressure, reduced thermal stability of the materials, and reduced bakeability.

Figure 5 shows a comparison of the pump down curves of an identical chamber with a stainless steel door and an acrylic glass door. In addition to the data points which every user can calculate manually from publicly available tables after an hour, complete pump down curves with a commercially available simulation program are also shown.

Plotting a reference curve in low as well as in high vacuum

Depending on the origin of the data in the tables, it is sometimes possible to achieve a good correlation. However, in the literature, a span of more than three decades is given for stainless steel. The large variation is due to different alloys, pre-treatments, surface finishing, and baking out.

From our model with the acrylic glass door, we can immediately see significant deviations from figures given in the literature. We would therefore recommend scaling, or even selecting new pumps, on the basis of the measured data. This means that we recommend plotting a reference curve in both the low vacuum and high vacuum range.

As a rule of thumb, it can be said that the outgassing rate of metals is relatively low while plastics provide much higher contributions to the total gas flow. Exceptions to this rule are found in metals such as zinc or brass alloys, which also exhibit very high outgassing rates. The outgassing rates of elastomers can be affected by the chemical composition and additives. Mechanical or thermal pre-treatment can drastically reduce the outgassing rate. So it pays to invest in vacuum compatible materials.

Before choosing a pump: analyzing pump down curves

Before investing in new pumps or vacuum chambers, analyzing a pump down curve should be obligatory. Deviations between a reference pump down curve and a measured curve often allow faults to be detected at a glance. Detailed analysis of a pump down curve allows for a better understanding of the processes involved and offers approaches to problem solving.

When moisture enters into the system, an external drying of the used components or the cleaning of the vacuum chamber is often better in achieving the target values for the down pump time than investing in larger pumps. In particular, the surface treatment of the chamber in the high vacuum is one of the most important parameters for the achievable ultimate pressure.

With its broad product portfolio, Pfeiffer Vacuum offers the optimal solution for various vacuum ranges and applications.

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