Tip of the Month/No. 6

The most common errors when using vacuum pumps and how to avoid them, Part 3 – Turbopumps

The ideal vacuum solution at the best price is almost always the preference from the viewpoint of the customer. This fact poses the danger that a less optimal pump solution is selected for cost reasons, a decision which could eventually cause the customer to experience less uptime and higher maintenance cost. Selecting reliable vacuum pumps and the corresponding accessories as well as sensible monitoring and operating modes will pay for themselves in the long run.

In the following, you will find a summary of the important information and insights for the operation, equipment selection, and maintenance of commonly used vacuum pumps. In this issue and in upcoming "tips of the month" we will show you the most common errors when using rotary vane pumps, Roots pumps and turbopumps as well as measures to avoid them.

It must be explicitly stated that the accompanying images are only examples and no conclusions should be drawn about the reliability of the brands shown.

3. Turbopump

The turbopump is a high- to ultra-high vacuum pump and essentially consists of a rotor and a stator. A rotating rotor disc and a stationary stator disc create a pump stage, which generates a specific compression ratio. By consecutively turning on multiple pumping stages that multiply themselves in the compression effect, high compression ratios of up to 10^{13} can be reached. Modern pumps use for example Holweck stages on the backing side, reducing the number of turbo stages without affecting the compression. At the same time, some manufacturers could increase the permitted foreline pressure to over 30 hPa, drastically reducing the size of the backing and enabling the use of diaphragm pumps for the first time.

Turbopumps without additional compression stages can be used for processes that are prone to condensation, sublimation, and particle formation, as the narrow gaps can lead to deposits, mechanical damage, and clogging.

3.1. Fore-vacuum Pressure

The fore-vacuum pressure can rise to over 30 hPa for pumps with additional compression stages. For pumps with pure turbo stages, the maximum fore-vacuum pressure is 2 – 3 hPa, but is depended on the pumped gas, e.g. for nitrogen 2 hPa and for hydrogen 0.5 hPa.

Exceeding the maximum pressures specified by the manufacturer can lead to bearing damage and, in extreme cases, total failure, due to the pump's overheating. The gas friction rises too high and the additional resulting compression heat cannot be dissipated. For pumps whose bearing and rotor temperature is not monitored, this is particularly critical and, in many cases, unavoidable. By using diaphragm pumps with final pressures between 2 – 5 hPa, one can operate the equipment in the vicinity of this border area.

Dry pumps, except for diaphragm pumps, do not have any outlet valves. Should the backing pump fail, the process chamber will be vented from the backing side, if the resulting drop in speed of the turbopump does not trigger an automatic venting process due to the rapid rise of the fore pressure. Abrupt venting of large chambers can cause the turbo rotor to tarnish due to the so-called helicopter effect in the casing.

In order to protect the turbopump, the manufacturers offer safety valves that serve to shut off the exhaust against the chamber immediately should the backing pump or fore-vacuum pressure fail.

The closing time must be correspondingly short. If fore pressure measuring is available, the valve can be controlled and operated using the pressure rise or the backing pump's failure signal.

3.2. Dimensioning the Exhaust Line
It is recommended to install the exhaust line and valves at least in the pump's nominal size, as significant pumping speed losses could occur due to adverse conducting values. Below is a slightly exaggerated example to illustrate the influence of the conductance value losses in an inlet line with a 25 mm diameter and a length of 100 mm. Effective pumping speed of a turbopump with a nominal pumping speed of:

60 l/s: 10 l/s
5000 l/s: 14 l/s

As can be seen, a turbopump larger by a factor of 80 produces just 40 % more pumping speed.

3.3. High and Fore-vacuum Connections
If the pump's high-vacuum flange is connected to the recipient, it is necessary to make the foreline flexible. If the foreline is rigidly connected, the pump casing cannot expand when it warms up, leading to improper material stresses. In this rigid connection the rotor cannot move freely and the remaining minimal imbalance can, over time, lead to bearing failures and can cause rotor damage.

Turbopumps are balanced to ensure low-vibration operation and optimal bearing durability. During a normal startup, depending on the rotor dynamics, they pass through certain resonance frequencies. Should these frequencies stimulate the natural frequency of the vacuum chamber, the frame, or the entire system, they can lead to a considerable increase of the frequency amplitudes; at these frequencies, the pump begins to vibrate strongly and becomes very loud. Frequently running through these frequency areas can lead to rotor damage and possible damage to the equipment or built-in vibration-sensitive components. Turbopumps with magnetic bearings are no exception. Therefore, it is advisable to determine the natural frequency of the system and to consult the pump manufacturer with these values. The vibrations can be prevented with reinforcements, additional weights, and design changes.

3.4. Securely Connecting the High-Vacuum Flange / Vacuum Chamber
Turbopumps, especially larger ones with magnetic bearings and bell-rotor designs larger than 1000 l/s, have high torques at their nominal speed, which are degraded in milliseconds when the rotor crashes. If the chamber is laid out improperly and the turbopump is mounted directly on it, deformation of the chamber can occur, and in the worst case the turbopump could twist or even detach from the chamber flange.

In recent years, driven primarily by the semiconductor industry, the pump manufacturers have identified and tested the moments and forces on the pump casings and inlet flanges using crash tests and containment analyses. It was found that the flange connection to the chamber should ideally be carried out in ISO-F. Turning the pump with an ISO-F flange is prevented by the slotted holes and by using ISO-CF with the mounting screws.

The pump manufacturers offer so-called mounting kits, which contain a sufficient number of clamps or mounting screws in the required material grade and the appropriate centering rings. Only this can ensure that the connection remains intact and sealed in case of a crash. The manufacturer's instructions in the operating manuals must be strictly followed.

3.5. Splinter Protection
It is advisable to insert a protective guard into the high-vacuum flange of the turbopump to avoid rotor damages due to falling debris. Depending on conductance losses, the pumping speed is reduced by up to 30 %, depending on the gas type. If possible, the turbopump should be placed upside down on the chamber, as foreign objects will fall out due to gravity. Ensure that the pump can be used for overhead operation.

3.6. Baking Out the Pump
When baking out the pump, the manufacturer's specified maximum high-vacuum flange temperatures of max. 120 °C must be observed. Exceeding the permitted temperature leads to overheating the pump and can lead to bearing or rotor damage. When baking, cooling the pump with water is required. Some manufacturers offer water cooling in UHV versions with ISO-CF-F flange by default. The bake-out process should take at least 6 hours.

3.7. Venting the Pump
Without venting, the turbopump will be contaminated with hydrocarbons after coming to a standstill when the pressure is balanced from the fore-vacuum to the high-vacuum side if rotary vane pumps are used as backing pumps. If no valve has been installed into the high-vacuum side, the contamination will spread into the recipient or appliance. For large chambers, the air is drawn in very quickly, which can result in possible rotor damage, as already mentioned under 3.1. Venting the pump with dry gas, nitrogen, or oil-free air prevents contamination and properly aerates the backing pump.

The pump can be safely vented using a venting valve at a certain speed, using the turbopump drive electronics. As the compression ratio of a turbopump also depends on the speed, the optimum initial vent should occur at about 50 % of the nominal speed and should begin at 20 % at the very latest. In addition to their factory settings, modern electronics allow for a certain flexibility in the venting speed. With proper venting, the recipient is also protected from contamination when using ball-bearing turbopumps.

There are processes during which pump-independent venting is preferred over the control system. This leads to a loss of the important link to the pump speed. Additional monitoring of the pump speed is not necessary when venting over the pump's drive electronics. When venting, the pump's inner surface is covered with dry nitrogen, which significantly shortens the evacuation time, as no difficult-to-remove gases or water can accumulate on the surface. The venting gas may not be let in from the backing side, as condensates, particles, and even oil could reach the high-vacuum side.

In unstable grids with frequent power failures, especially when overloaded by the use of air conditioners in the summer, it is advisable to use a so-called power failure venting valve that can automatically vent the pump and properly shut it down during a power failure. Frequent venting, especially over the high-vacuum side, leads to excessive heating of the pump, mechanical stress, and shortened bearing durability due to massive amounts of gas friction.

3.8. Magnetic Fields and Radiation
Magnetic fields generate eddy currents in the rotor of a running turbopump, which warm and quickly overheat the rotor. The energy required is taken from the electronics and leads to a significant increase in the motor current, which represents a direct value for the heating of the rotor.

The maximum permitted magnetic fields specified in mT (Milli Tesla) are given in the pump manufacturer's operating instructions. If these values are exceeded, the pump must be shielded. If the distribution of the magnetic field is known, it must be rearranged.

Neutron and gamma radiation of varying intensity and duration occurs around particle accelerators. This radiation destroys drive electronics and frequency converters mounted on the pump, both of which have sensitive power transistors and diodes. In this case, the drive electronics must be installed a safe distance away from the radiation, using connecting cables. The same applies to measuring equipment. Active sensors must be avoided, as the sensor electronics are also destroyed by the radiation.

3.9. Process Suitability
It is very important to ensure that the turbopump is suitable for the process. Detailed advice from the pump manufacturer and accurate information about the process and its characteristics through the operator are required. There is potential for improvement on both sides here. For corrosive processes,

especially in the semiconductor industry, it is necessary to operate the pumps with sealing gas, to use synthetic PFPE oil for ball-bearing pumps, and to use corrosion resistant materials on the rotors, such as nickel or ceramic coatings.

The sealing gas, such as dry nitrogen, forms an outstanding corrosion and dust protection for the ball-bearings in connection with a labyrinth seal. When sizing the backing pump, this additional gas load must be considered. Offered sealing gas valves regulate the optimal sealing gas flow. The sealing gas pressure specified in the operating instructions must be observed.

When pumping oxygen in concentrations higher than atmospheric oxygen levels, it is important to ensure that the mineral oil is not oxidized by the oxygen and loses its lubricating properties. This can be prevented by using nitrogen as a sealing gas and/or PFPE oil.

For processes with a tendency to form deposits, for example in CVD, the coating process will continue on the rotor and casing parts facing the process chamber. This leads to imbalance and vibrations that could cause a rotor crash. In such processes, it is important to include precautions and additional supervision even while designing the process chamber.

If possible, the turbopump should be installed upside down, so that gravity can pull the dust down and make it harder for dust to accumulate in the pump. It would make sense to install a baffle plate to prevent dust from falling directly into the running pump. If an overhead installation is not possible, the pump can be installed sideways on a T-frame at a 90 degree angle. The backing port should point downwards.

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Figure 1: Rotor crash caused by imbalance due to heavy levels of coating