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Diaphragm Vacuum Pumps for Backing Turbo Pumps

Up to 40,000 hours maintenance-free operation of diaphragm pumps

vacuubrand

Vakuumtechnik im System

FIGURE 1: VACUUBRAND MD 4 NT diaphtagm vacuum pump

1. SELECTING A PUMP FOR BACKING TURBO PUMPS

Turbo pumps are nowadays in widespread use for various applications. Apart from special applications and for large pumping speeds, more and more turbo pumps come with an integrated molecular drag stage. This additional pumping stage improves the backing pressure capability of the turbo-drag pump to the mbar range, which is reachable with diaphragm pumps. Therefore, backing pumps are no longer limited to oil-sealed rotary vane pumps. This is a great advantage, since the combination of a turbo pump with a diaphragm pump results in a very compact, powerful and oil-free system. Maintenance demands of diaphragm pumps are much less than for rotary vane pumps, and avoids the messy oil changes and waste oil disposal. Oil-free operation also eliminates the risk of oil backstreaming or even oil migration into the turbo pump or into the high vacuum chamber.

Diaphragm pumps offer advantages over other backing pump technologies, as well. They do not have any sliding seal, in contrast to scroll or piston pumps. These sliding seals (made, e.g., of PTFE / carbon) often cause wear debris which may creep into the turbo pump. This black dust may damage the turbo pump and even spoil the high vacuum chamber. Therefore, diaphragm pumps are preferable for all clean applications.

For applications with corrosive gases and vapors, chemical resistance is an important attribute of the backing pump. Diaphragm pumps are oil-free and all wetted parts can be manufactured from fluoroplastics. These socalled „chemistry diaphragm Pumps“ deliver reliable, low maintenance service even with highly corrosive gases and vapors.

For selecting a backing pump - especially a diaphragm pump - it is important to consider:

- **THE ULTIMATE VACUUM OF THE BACKING PUMP**

The ultimate vacuum of the backing pump should be better than the maximum permissible backing pressure of the turbo pump, of course. At low gas flow, the ultimate vacuum of the backing pump is important for the performance of the complete vacuum System.

- **THE PUMPING SPEED OF THE BACKING PUMP AS A FUNCTION OF ITS INLET PRESSURE (THIS CORRESPONDS TO THE FOREVACUUM OF THE TURBO PUMP)**

The pumping speed especially at medium and low pressures is decisive for the pump down time and the permissible gas flow of the vacuum system. If the backing pump is not able to handle the gas flow, the forevacuum level worsens. If that happens, the turbo pump may be overloaded and switch off. To avoid this problem, the backing pump should have a constant and high pumping speed down to low pressures.

▶ RELIABLE START UP AGAINST VACUUM AND VACUUM TIGHT SWITCH-OFF (LOW ANTISUCKBACK LEAKAGE RATE)

The backing pump must not vent backwards in the event of a power failure; this would vent the complete vacuum system. In addition, the backing pump must be able to start against vacuum. Many users undervalue these aspects, but they a re very important for high process reliability in case of a power interruption.

▶ DIAPHRAGM LIFETIME

Diaphragm pumps with fixed motor speed often have diaphragm lifetimes shorter than the typical maintenance interval of turbo pumps (typ. 40,000 h). Therefore, the diaphragms have to be exchanged more frequently than the turbo pump maintenance interval would require. However, new results with planar diaphragms show similar diaphragm lifetimes to turbo pump maintenance intervals (see below).

▶ CONSTANT PERFORMANCE OVER THE DIAPHRAGM OPERATING TIME

Many common diaphragm pumps show a decline in pumping speed after a few months. During the same period, the ultimate vacuum worsens. This is especially problematic when diaphragm pumps are used to back turbo pumps, as the diaphragms have to be replaced even earlier. This effect can be prevented by special (planar) diaphragm designs (see below).

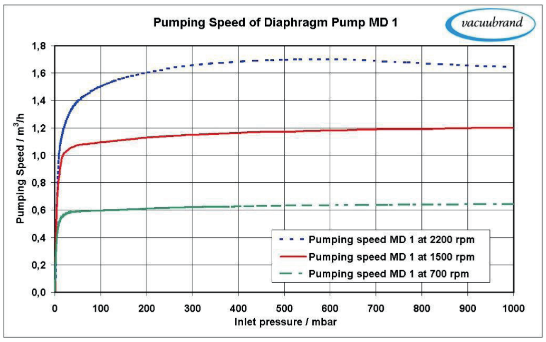

FIGURE 2: Pumping speed curves of VACUUBRAND MD 1 diaphragm pump

▶ DRIVE SYSTEM

Variable motor-speed diaphragm pumps produce better ultimate vacuum if the motor speed is reduced. This offers exceptional advantages when backing turbo pumps, as the turbo pump then works in a better operating range. At the same time, the lower motor speed improves diaphragm lifetimes and reduces the noise, vibration and power consumption of the diaphragm pump significantly.

▶ FURTHER IMPORTANT CRITERIA (DEPENDING ON THE APPLICATION) ARE COMPACTNESS, NOISE, VIBRATION, MOUNTING ORIENTATION AND CHEMICAL RESISTANCE.

SUMMARY

State-of-the-art turbo pumps with integrated molecular drag stage can be operated with fore-vacuum levels in the single-digit mbar range/ per mitting oil-free diaphragm vacuum pumps to be used for backing. Because of advances in diaphragm technology and electronic drives for variable speed operation, diaphragm Pumps are now even more compact, powerful and reliable. Long term tests indicate diaphragm lifetimes in excess of 40,000 hours and ultimate vacuum within specifications over the entire test period. Variable speed drive systems also extend maintenance intervals for backing pumps to the point at which they are comoarable to those of turbo molecular pumps.

2. DIAPHRAGM VACUUM PUMPS

For pumping speeds up to 12 m^3/h (200 l/min, 7 cfm) diaphragm vacuum pumps are often the most suitable backing pumps. For applications with non-corrosive gases, for example, very clean conditions are often required; this requirement excludes oil-sealed rotary vane pumps, or pumps producing dust like scroll or piston pumps. For applications with corrosive gases and vapors, chemistry diaphragm pumps are also virtually the only choice, as no other vacuum pump type offers comparable chemical resistance.

But design differences among diaphragm pumps can also contribute to the advantage that diaphragm pump technology offers compared with alternatives. Some common pumps use molded diaphragms, for example, in which the diaphragm is not supported by external solid parts. In contrast, planar diaphragms are supported by solid metallic or plastic parts above and below the diaphragm. These solid components guide the planar diaphragm with exceptional precision and ensure long term stability. Figure 1 shows a cross sectional view of a state-of-the art four cylinder diaphragm pump (VACUUBRAND MD 4 NT) with planar diaphragms.

In ***Fig. 1***, the aluminum, polygonal diaphragm supporting disc is visible immediately adjacent to the connecting rod. The planar diaphragm is secured between the supporting disk and clamping disc (which looks like a spherical section on the diaphragm in ***fig. 1***) and guided in a precise path that minimizes fatigue.

In standard duty pumps, the clamping disc is made of aluminum, and the diaphragm and valves are made of flexible, long-wearing, fabric-reinforced FKM. The diaphragm separates the pump chamber from the drive chamber hermetically, ensuring that process vapors are isolated from the pump mechanism. The head cover, visible next to the diaphragm in the figure, is also made of aluminum in the standard duty pumps. The housing cover directs the gases to and from the cylinders and is in this case machined of solid aluminum for exceptional gas tightness.

In „chemistry diaphragm pumps", the clamping disc is made of chemicalresistant fluoroplastics with a „stability core", and the fabric-reinforced FKM diaphragm is protected by a PTFE foil. The head cover is also made of fluoroplastics with a stability core for consistent, long-term performance. The valves in chemistry pumps are made of FFKM or PTFE. The complete vapor flow path is made of fluoroplastics for exceptional chemical resistance.

The uniformity and flexibility of the planar diaphragm design result in a pumping speed curve that is close to ideal. ***Fig. 2*** shows pumping speed curves of the MD 1 diaphragm pump - a similar design to the MD 4 NL above - at three different motor speeds.

It is evident that the pumping speed is very constant over the full inlet pressure range for all motor speeds. Other diaphragm pumps, such as those with molded diaphragms, may report similar specifications for maximum pumping speed (free air displacement) and ultimate vacuum - the usual catalog values - but have much smaller pumping speeds in between the two performance endpoints where the real pumping work occurs. The performance of such pumps suffers by comparison with planar diaphragm designs when measuring pump down time or permissible gas flow.

3. TESTING DIAPHRAGM PUMPS FOR BACKING APPLICATIONS

The planar diaphragms of VACUUBRAND oil-free pumps have typical diaphragm lifetimes in excess of 20,000 hours. At 8760 hours per year, this makes lifetime "tests-to-failure" very time-consuming. For testing of most components, VACUUBRAND uses accelerated aging tests. Since diaphragm lifetime depends on the number of strokes, at twice the motor speed the diaphragm lifetime is halved. Actually, the wear is even larger, as the diaphragm gets hotter at high speed. High gas loads also increase wear, so tests at high speed and high load provide representative component qualification within one year. Other considerations must be taken into account to extrapolate from these tests to a realistic estimate of diaphragm lifetime that is valid for "normal" operating conditions.

For applications like backing of turbo pumps, for example, the "normal" operating condition is at ultimate vacuum. Pumping down from atmospheric pressure typically happens less than once a day, and most of the time the backing pump runs at close to ultimate vacuum. For reliable operation of a backing pump, therefore, the ultimate vacuum performance is possibly more important than the diaphragm lifetime. If the ultimate vacuum of the diaphragm pump degenerates over time to the point at which it is no longer sufficient for backing the turbo pump, the diaphragm has to be replaced even if it did not fail completely. Common diaphragm pumps with molded diaphragms often demonstrate such a decline in vacuum performance over time. Therefore, a continuous measurement of the ultimate vacuum during the test period is quite worthwhile for assurance that the backing pump is continuing to provide the needed ultimate vacuum.

VACUUBRAND started such a long term test with six MD 1 diaphragm pumps several years ago. The pumps run permanently at ultimate vacuum which is measured and recorded every 30 sec. ***Fig.3*** shows this record.

All of the pumps have remained within the specification for new pumps over the full operating time of more than 40,000 hours. None of the 24 diaphragms (six pumps with four diaphragms each) failed within the 43,000 hour test period. The apparent slight variations (+/-0.4 mbar) in the ultimate vacuum are caused by the vacuum gauges. These results prove the exceptional long term reliability and performance of VACUUBRAND diaphragm pumps, especially for applications that require continuous duty at or near the ultimate vacuum.

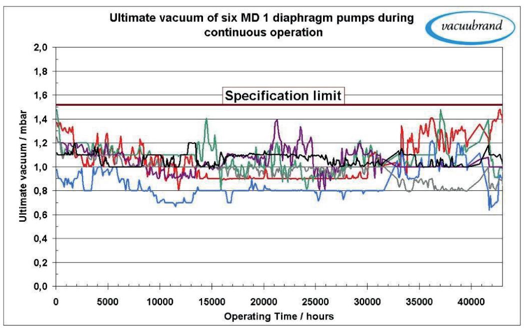

FIGURE 3: Ultimate vacuum of six VACUUBRAND MD 1 diaphragm pumps over five years

4. DRIVE SYSTEMS: PERFOLMANCE AND EFFICIENCY

This long term test was performed with pumps with single phase motors. So the pumps run at about 1500 rpm, irrespective of actual demand. For optimum performance and efficiency, variable speed drive systems offer significant advantages, since they permit the adjustment of the motor speed to the actual demand. This can be done either by an external control signal generated by the vacuum application (or the turbo pump), or by a vacuum controller measuring the for-evacuum level and adjusting the motor speed accordingly.

Lowering the motor speed not only reduces vibration, noise and energy consumption, but also improves the ultimate vacuum. In addition, the diaphragm lifetime (and, hence, maintenance interval) is extended. For example, if the pump occasionally pumps down from atmosphere at 2200 rpm but operates most of the time at 700 rpm, the diaphragm lifetime should be doubled. In consideration of the results shown above, one can speak of a virtually maintenance-free backing pump.

The VACUUBRAND MD 1 diaphragm pump is available with conventional single phase AC motors for direct mains operation at line voltage (***fig.4:*** left hand) and with a brushless 24V DC motor (***fig.4:*** right hand). The AC motor is available in a worldwide motor (wide-range voltage) version. Both pump types start reliably against vacuum, of course, and offer all of the benefits of corrosion resistance and long service intervals described earlier. The brushless DC motor is maintenance free.

FIGURE 4: VACUUBRAND MD 1 diaphragm pump with AC (left) and DC motors (dght)

The DC motor model is even more compact than the AC motor version, and offers variable speed operation in the range of 200 rpm to 2200 rpm. The motor speed can be adjusted by analogue or digital control signals, or set manually. The patented start-up system of the motor electronics lowers the current consumption substantially during start-up. This offers the further spacesaving opportunity of a smaller DC power supply.

Both pump types rely on VACUUBRAND's patented "flying motor" approach for bearings, making the pumps even more compact and silent. In addition, the drive electronics for the brushless DC motor are fully integrated into the pump. This "mechatronic" solution leads to an unmatched compactness for the ultimate vacuum and pumping speed delivered.

Referring again to ***Fig. 2***, we can see the pumping speed of the DC pump at various motor speeds. At 2200 rpm, the pumping speed reaches 1.7 m^3/h (28 l/min, 1 cfm). By sacrificing a bit of pumping speed and operating the motor at a low speed like 700 rpm, an ultimate vacuum as low as 1 mbar can be reached. These performance values are the direct consequence of the advantages of variable motor speed afforded by the DC motor. In turbo backing applications, this control offers the dual benefit of shorter pump down times and better ultimate vacuum for the high vacuum system.

FIGURE 5: VACUUBRAND MV 2 NT VARIO diaphragm pump, ultimate vacuum 0.3 mbar

Larger diaphragm pumps are also available with 24V DC drives that offer comparable performance advantages of these. VACUUBRAND refers to these designs as its VARIO-SP (i.e., VARIO-System Pump) line. These are ideal for integration into compact systems, especially if a 24V DC supply is built-in anyway. All these pumps can be mounted in any position and run with low noise and vibration.

Besides their small size, an added benefit for integration of these pumps into compact equipment is their energy efficiency, which results in less energy consumption and less waste heat. For example, the MD 1 diaphragm pump needs around 100 W at ultimate vacuum with an AC motor, but only 24 W when maintaining ultimate vacuum with a DC motor operating at 700 rpm. At ultimate vacuum, virtually all of the electrical energy is transferred to waste heat (since there is essentially no vapor movement at ultimate vacuum, by definition). Therefore the DC pump releases only a quarter of the waste heat of the comparable AC pump. This has many positive implications for, e.g." ventilation requirements inside the equipment, air conditioning loads and, of course, energy costs.

VACUUBRAND variable speed pumps are also available with a vacuum controller for operation as standalone units. The vacuum controller uses an integrated vacuum gauge to monitor conditions continuously and then adjusts the motor speed automatically according to actual demand. The gauge/controller combination avoids the need for an additional vacuum gauge. ***Fig. 5*** depicts such a complete vacuum pump system (VACUUBRAND MV 2 NT VARIO), consisting of a variable speed diaphragm vacuum pump (ultimate vacuum 0.3 mbar) and a vacuum controller.

In summary, planar-diaphragm vacuum pumps show exceptional performance and reliability over very long operating times. Diaphragm pumps are oil-free and do not generate wear debris (dust) like scroll or piston pumps. Integration of the "flying motor" drive system into the pump results in a design of unmatched compactness, low weight and quiet, nearly vibration-free operation that facilitates integration into vacuum-dependent equipment and instrumentation. Variable speed drive systems like brushless 24V DC motors or self-optimizing systems with vacuum controller open many additional design options for laboratory users and original equipment developers.

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