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HOW TO CHOOSE A DIAPHRAGM PUMP

Understanding how diaphragm pumps work can help apply them properly

Diaphragm pumps are just one of the many types of oil-free pumps that are presently being used in many applications to avoid the problems of oil vapor contamination that affect many of today's stringent processes. Commercially available diaphragm pumps contain no sealing or lubricating oils within the pumping head, and this means that you can depend upon producing a vacuum where the residual gases are entirely free of oil vapor. All vacuum pumps, oil-free or not, have differing operational characteristics that make them fully suitable for one application and totally unsuitable for another. Diaphragm pumps are no exception. Matching pump-type to application can be difficult, but a fuller understanding of the modes of operation in terms of strengths, weaknesses, and peculiarities can relieve some of the difficulties.

Diaphragm pumps fall under the overall category of positive displacement pumps. Pumps in this category all trap an aliquot of gas within a volume and then compress the gas by contracting the volume by some mechanical means to force the gas out. The volume is then expanded mechanically to allow more gas to enter before repeating the cycle. In a diaphragm pump, the pumping volume is changed by moving a flexible diaphragm up and down to produce the expansion/contraction cycle. These pumps are fitted with simple inlet and outlet flapper or reed valves made of flexible materials that are operated by pressure differential to open and close them as required to produce the pumping action. A single pumping cycle can be described fairly simply in terms of the diaphragm's motion.

Down-Stroke

The flexible diaphragm is pulled down, and this results in an increase in the volume of the pump head's internal space. The expansion of volume causes a pressure drop inside the pump head; and

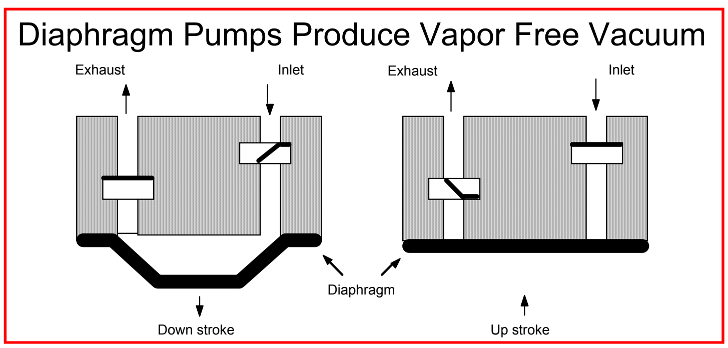
1. The pressure inside the pump head's internal volume becomes less than the inlet pressure, and the exhaust pressure,
2. The higher pressure at the inlet forces the inlet flapper valve open,
3. The higher pressure at the exhaust holds the outlet flapper valve closed,
4. The higher pressure at the inlet forces gas from the inlet through the inlet valve into the pump head's volume.

Up-Stroke

The flexible diaphragm is pushed up, and this results in a decrease in the volume of the pump head's internal space. This volume contraction causes compression of the gas which results in a pressure increase inside the pump head; and

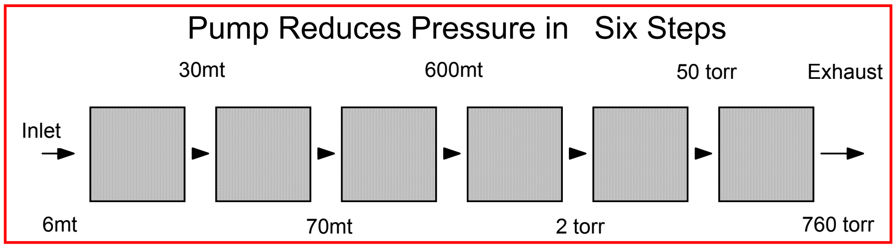
1. The pressure inside the pump head's internal space is higher than the inlet pressure and the exhaust pressure,
2. The higher pressure inside the pump head's internal space holds the inlet valve closed,
3. The higher pressure inside the pump head's internal space forces the exhaust valve open,
4. The higher pressure inside the pump head's internal space forces gas through the exhaust valve and out of the pump.

This description of a single-head pump can be taken only as a representative view of all diaphragm pumps in terms of principle of operation. Beyond this simplified view, there are wide variations in design that must be taken into account when matching a given pump to a given application.



Cross-sectional view of a diaphragm pump in operation.

The ultimate attainable vacuum level is obviously an important operational parameter. Pumps are commercially available that will produce ultimates ranging from several hundred torr to the 10^{-4} torr range. One method of achieving lower ultimates is by staging pumping heads in series. For example, a single-head pump that blanks-off at 500 torr might produce a blankoff pressure of 100 torr if two heads of that same design are arranged in series. Any single pumping head will only be able to produce a certain compression ratio between the inlet and exhaust pressure. When a second head is added in series, one head supports the other by lowering the pressure between the heads and allowing the head closest to the chamber to produce a lower chamber pressure even though its compression ratio is the same as the head closest to the atmosphere. If gauge tubes are mounted between the heads of a multi-stage pump, discreet pressure steps between heads that show higher and higher pressures as one moves toward the last stage before atmospheric pressure can be easily observed. Although there is no theoretical limit to how low an inlet pressure can be achieved by staging heads in series, there are a number of practical problems and limits to contend with when designing a working pump.



Schematic view of the pressure reduction steps in a 6-stage diaphragm pump.

Flapper valve design can have a profound effect on a multi-stage pump's ultimate pressure. Since the inlet and outlet valves are opened and closed by pressure differential, they must be flexible enough to operate at small pressure differentials. Thin and flexible metal strips will continue to operate at pressures down into the tens of torr region, but will usually cease to operate at lower pressures. For lower pressures, elastomer valves are usually required.

Vacuum seals can be another problem to overcome. The elastomer diaphragm is not only held around its outer diameter to anchor it when the center is moved up and down during the pumping cycle, but he same mechanical holding action has to provide a vacuum seal. When you consider the difficulty of making a vacuum-tight high vacuum seal with a flat elastomer gasket between two flat flanges, the sealing problems become more obvious. Additionally, many commercially available pumps use head-to-head tubing seals that are not suitable for low pressure sealing. The permeation rate of gases from the atmosphere through the large exposed area of the elastomer diaphragm also comes into play when lower ultimate pressures are desired. Consequently, no diaphragm pump can be considered to be hermetically sealed.

Diaphragm lifetime can also be a major concern. Any flexible material that is constantly flexed will encounter fatigue and fail at some point. When making elastomer diaphragms, it is impossible not to have an occasional weak spot in the sheet. A weak spot will obviously result in premature failure. However, average diaphragm lifetimes of 10,000 hours can be routinely achieved. The key to extending the time between failure is to maintain lower diaphragm temperatures. heat is generated within the pumping head by both heat of compression of the gases being pumped and mechanical heat generated by the pump's driving mechanism. Heat will cause both physical and chemical changes in the elastomer material and cause failure. Since the diaphragm is exposed to this heat, it is necessary to remove it by some means. At high pressures where there is a fairly large gas flow through the pump, the heat from heat of compression is carried away by the amount of gas passing through the pump. At low pressures, there is less heat of compression and only mechanically generated heat is a problem. The main heat problem occurs at intermediate pressures where heat of compression is still fairly high but gas flow is too low to carry away all the heat. Although many pumps have air cooled motors that provide some air flow over the atmospheric pressure side of the diaphragm, heat builds up in the mass of the pump heads themselves. This heat must be removed to avoid too much heat exposure of the diaphragm. Additional air flow over the heads will provide sufficient heat exchange, but exposure to still air is not sufficient. The best results are obtained by additional fan cooling, especially in a ducted arrangement, that moves cooling air directly around and over the surface of the pumping heads.

Pumping speed, in diaphragm pumps, is controlled by the total volume (swept volume) of the pumping head’s internal volume and the cyclic rate of expansion/contraction cycles. This imposes a pumping speed limit in that the cyclic rate can only be so high in a practical mechanical system and that the diameter of the diaphragm can only be so large. The pumping speed limits on a single head can be overcome by operating several heads in parallel to make the total speed additive to the total of each head’s speed. Thus, mixtures of heads in series and parallel can be combined to produce a higher pumping speed and a lower ultimate pressure at the same time.

The gas or gas mixtures to be pumped is an important consideration with all vacuum pumps. Gas mixtures containing condensable gases such as water vapor or solvents will result in their condensing somewhere within the pump. This problem is common to all positive displacement pumps including oil-sealed mechanical pumps. The amount of condensation encountered depends upon both the amount of condensable gases within the pumped gas, such as humidity, and the way the pump is operated. For example, a large pump that evacuates a small chamber on a high duty cycle will tend to build up condense within it. This is due to the fact that the amount of gas passing through the pump per cycle is not high enough to physically flush out the condensed material. A large pump on a small load lock would be a good example. Adding a gas ballast valve to pass a small amount of gas through the pump’s inlet or occasionally “burping” the pump by allowing full gas flow at atmospheric pressure for several minutes will usually clear the condensed material.

Other gas problems result in pumping light gases which are compressed efficiently, but can easily back-diffuse. This can be seen by directing a small flow of helium near the exhaust of a multistage pump. An almost immediate and dramatic pressure rise can be detected by a gauge at the inlet. A small gas ballast flow can continually sweep light gases out of the pump. Noxious, explosive, or poisonous gases should be utterly avoided. No diaphragm pump is hermetically sealed and leaks into the atmosphere are possible. An even more important consideration is that a diaphragm can fail and release the gases at any time. Particle-bearing gases are also an application problem because they can collect in the pump and cause excessive diaphragm wear. One final consideration is oil. Replacing an oil-sealed pump with an oil-free diaphragm pump without cleaning the pumping line will cause oil to condense in the pump and cause valve problems that require the pump to be cleaned.

Re-starting a diaphragm pump after being turned OFF or after a power interruption can often be a problem. Some pumps will remain under vacuum and others will slowly vent back through the pump under these conditions. Additionally, a pump with two or more stages will often trap vacuum within one of the pumping heads and make re-starting almost impossible when there's vacuum at the inlet. This causes the motor to overheat and cause motor and diaphragm damage due to the excessive heat. It's a definite advantage, then, to provide a solenoid valve at the inlet to ensure that the chamber remains at vacuum. Then, a solenoid valve can be installed just before the first pumping head to allow a full flow of atmospheric air through the pump to ensure easy re-start. The best sequence is to use timers to allow venting flow for a short period before closing and then to open the inlet valve. This sequence also has the advantage of flushing out condensed liquids. Diaphragm pumps with this valving system built-in are commercially available, but any pump can be modified to include them.

Diaphragm pumps can be successfully applied to many clean vacuum applications, but they must be applied on the right applications. Knowledge and understanding of the pump's operating principles will allow a successful choice in matching pump to application.

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