Educational Guide to Vacuum Coating Processing

Vacuum Technology:

Mechanical Vacuum Pumps

Mechanical pumps are positive-displacement pumps that take a large volume of gas at low pressure and compress it into a smaller volume at higher pressure. Some mechanical pumps can be used as air compressors. The earliest vacuum pumps were mechanical pumps. In 1905, Gaede developed a mechanical pump that is very similar to the oil-sealed rotary vane pumps used today. Many mechanical pumps have multiple stages operating from a common motor and shaft. Mechanical pumps can be either belt-driven or direct-drive. Some direct-drive pumps can be disassembled by separating the pump from the motor, leaving the manifolding on the system. This is particularly useful when pumping hazardous gases where the pumping manifold can stay sealed while changing the pump motor.

Mechanical pumps are used to "rough" a vacuum system from atmospheric pressure, through the viscous flow range, to a low pressure (~100 mTorr), where the pumping system is switched from the roughing system to the high-vacuum pumping system. By only using the mechanical pump in the viscous flow range, backstreaming of oils from the mechanical pump into the vacuum system is minimized. Appropriately sized zeolite-containing oil-traps can be used in the roughing line to further minimize oil backstreaming.

Mechanical pumps are used to "back" high-vacuum pumps, and the pumping capability should not be restricted by the conductance between the mechanical pump and the high-vacuum pump. The mechanical pump is connected to the high-vacuum pump using a foreline manifold. The foreline pressure of the diffusion-type high-vacuum pump is an important factor in contamination control. If it is too high, backstreaming from the diffusion pump into the processing chamber occurs. If it is too low, backstreaming of oil from the mechanical pump into the diffusion pump occurs.

The most common mechanical pumps are the single and multi-stage oil-sealed mechanical pumps, such as the rotary vane pump shown in Figure 1. The vanes are held in contact with the wall by the action of the spring. These pumps are available to about 100 cfm (cubic feet per minute) pumping capacity. When oil-sealed mechanical pumps are used with chemicals or when particulates are formed in the processing, oil filtration systems should be used. These filter out particulates and neutralize acids in the oil. The pumps can be air-cooled or water-cooled, and the oil-filtration system can include an oil cooler. Many mechanical pumps are equipped with a ballast valve to allow the introduction of dry diluent gases (e.g., dry nitrogen or dry air) directly into the pump intake, as shown in Figure 1. These diluent gases reduce the partial pressure of condensable vapors so that liquids do not condense when compressed in the pump. When pumping corrosive materials, the internal parts of the pumps can become corroded. To prevent this, the internal surfaces should be continuously coated with oil by splashing action—this may be achieved by having a high gas throughput using the ballast valve. Also, the pump should be run hot in order to help volatilize liquids in the oil. Contaminant fluid in the pump oil degrades the performance of the pump to the point that the lowest pressure attainable is the vapor pressure of the contaminant fluid. Fluids in the oil also cause frothing that presents sealing problems in the oil-sealed pumps. Frothing can be observed through the oil-level viewing window.

Mechanical pumps generally use hydrocarbon oils for sealing. When pumping reactive chemical species, hydrocarbon oils may be easily degraded. The perfluorinated polyethers (PFPE)—which only contain fluorine, oxygen, and carbon—may be used to provide greater chemical stability; however, these pump oils have inferior lubricating properties compared to the hydrocarbon oil. When using this type of oil, the mechanical pump may have a sump heater to decrease the viscosity of the oil, particularly for start-up.

If the mechanical pump stops turning due to power failure, a belt breaking, or a bearing seizing, the pump may "suck-back"—bringing air from the high-pressure side back through the pump. This will suck some of the oil out of the pump into the foreline. This can be avoided by having a "check-valve" in the pump, or by having a ballast valve or orifice in the foreline that brings the foreline up to pressure without having to suck-back through the pump (fail-safe design). The temperature of the pump should be monitored, and overheating should be detected and alarmed. The oil-level in the mechanical pump should be routinely checked and periodically changed. Vibration from the mechanical pumps should by isolated from the vacuum system by means of flexible connections.

The mechanical pump is typically exhausted outside the building. The exhaust manifold of the mechanical pump should not introduce a back-pressure during startup and should be sized accordingly. The exhaust line should have an oil "demister" that condenses oil vapor in the exhaust line and lets it flow back into the pump. Some vacuum processing, such as etching, can generate hazardous gases that can condense in the pump oil. For example, a chlorine-containing gas along with water or oxygen can produce phosgene ($COCl_2$)—a poisonous gas. If the pumps are used to pump hazardous materials, the pump oil should be treated as hazardous waste and disposed of accordingy.

Oxygen is used in some PVD processing. Compression of pure oxygen in contact with hydrocarbon oils may cause an explosion if there is a hot-spot in the chamber. When compressing oxygen in contact with a hydrocarbon oil, a less-explosive gas mixture, such as air, should be used. Alternatively, a ballast valve or ballast orifice can be used to dilute the gas mixture to a less-explosive composition, and/or oxidation-resistant pump oils can be used.

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Higher pumping speeds are provided by single and multistage "blowers," which use close mechanical tolerance for sealing. The most common types are the Roots (lobe) blowers and "claw" blowers, shown in Figure 1; but other types, such as screw, scroll, and piston pumps, are available. These pumps are sometimes called "dry pumps" since they do not use oil for sealing. Dry pumps often use oil-lubricated bearings; so they really are not oil-free. However, they do minimize the potential of oil contamination in the deposition system. Dry pumps are more tolerant of particulates and vapors than are the oil-sealed mechanical vane pumps. They can have gas injection ports to allow the introduction of purge gases that aid in sweeping particulates through the pump. The temperature of a blower pump should be monitored, and overheating should be detected and alarmed. Where oil is used to lubricate the bearings, the oil level should be routinely checked and periodically changed.

Blowers generally do not exhaust to atmospheric pressure since compression of large amounts of gas to high pressures leads to extensive heating. Mechanical pumping packages with a blower backed by an oil-sealed mechanical pump capable of pumping rates greater than 10,000 cfm are available. Often the pumping chamber of the dry pump becomes contaminated with oil from the oil-sealed mechanical pump and thus becomes "less dry" with use.

The diaphragm pump is a mechanical dry pump that compresses the gases by a flexing diaphragm and can be used when the gas load is not high. Some diaphragm pumps have an efficient pumping range of 10 Torr to atmospheric pressure, with a gas throughput of 1.5 liters/sec or so, and an ultimate vacuum of 10^{-6} Torr. The diaphragm pump can be used to back a molecular drag pump or a turbomolecular pump with molecular drag stages, making a very oil-free pumping system for low throughput pumping requirements such as leak detectors.

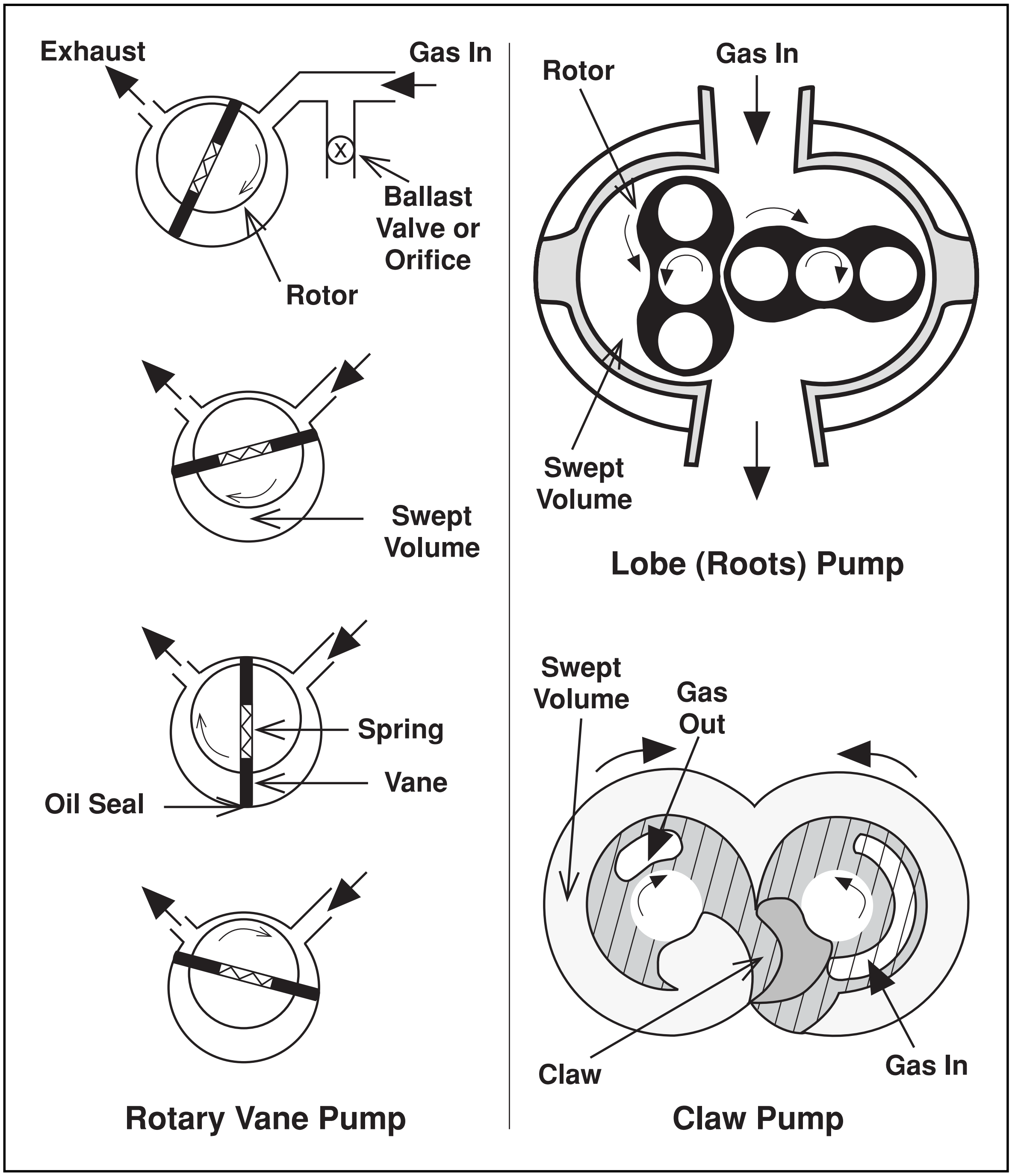

Figure 1: Mechanical pumps.