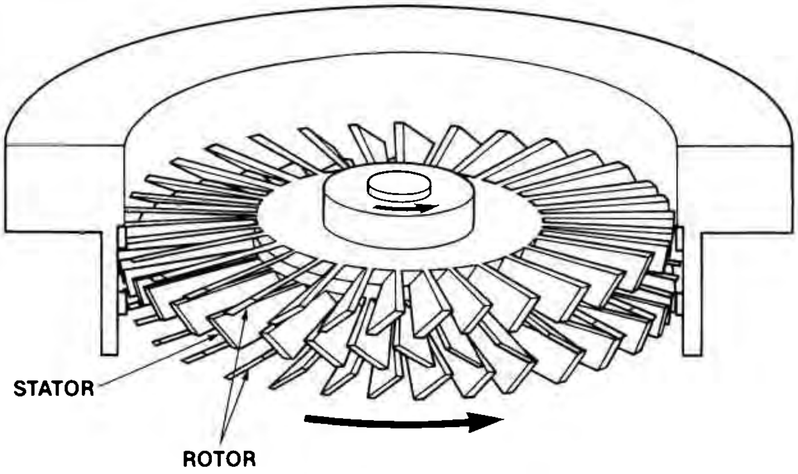
Components



The turbo pump is mainly composed of rotating and fixed disks. These are called rotors and stators, respectively. The rotor disks are arranged alternately with the stator disks. On each disk are blades. A disk may have from 20 to 60 blades. The number of blades on a disk, the blade length, width, spacing and rotational speed determine its ability to pump gases.

Each rotor and stator disk can be called a compression stage. A pump may have as many as ten to forty stages. The rotor is driven by a motor capable of reaching speeds from 9,000 rpm to 90,000 rpm, depending on the size of the pump. The motor is typically powered through a special power supply. Compressed gases are expelled from the pump via a foreline which must be evacuated by some type of forepump.

The primary source of vibration of a turbo pump is the residual imbalance of the rotor assembly. This imbalance causes an acceleration in the radial direction of the pump rotor, appearing as a displacement of the inlet flange "side to side." Typically, this displacement is of the order of 0.02 microns (2×10^{-8} meters) and is inconsequential for the majority of turbo pump applications.

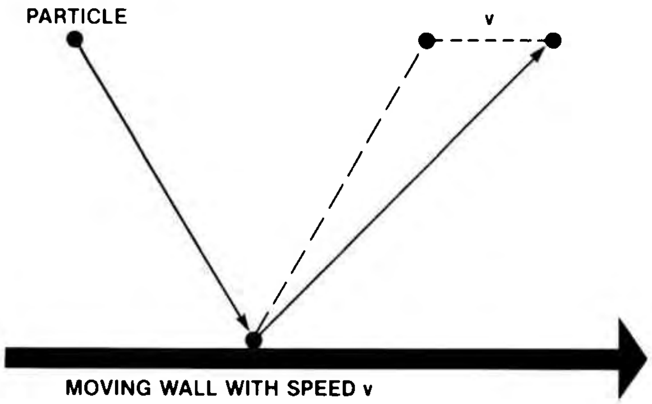
For vibration sensitive applications such as scanning electron microscopes or focused ion beam systems, vibration isolators are available that reduce the vibration level by an additional factor of ten to thirty times.

With turbo pumps, the vibration is at a relatively high frequency (near the controller output frequency) and is much easier to isolate than the low frequency vibration present in other types of mechanical pumps.

How the Pump Works

Pump Operation

When a gas molecule strikes a moving surface, it keeps its own speed. It also picks up a little more speed and a different direction from the contact with the moving surface. By this process, the movement of molecules can be directed, and pumping takes place.



PRINCIPLE OF THE TURBOMOLECULAR PUMP

The turbo pump works much like this; however, it adds blades to the moving surface plus a close-coupled stator. The stator also has blades. Each blade, when moving, will give some momentum to the gas molecules it hits. Each rotor blade, then, acts as a molecular pump. The result? Much greater momentum, speed, and direction are given to gas molecules entering this pump.

In the molecular flow range, the gas particles collide much more often with the moving blades than with each other. The effect of moving blades on the gas particles is highest in the molecular flow range. Pumps operating on this principle are called molecular pumps.

On the stages closest to the inlet, the blades have a large angle so as to pump at a faster rate, because more "open" space allows more access to the chamber. The blades closest to the foreline have a small angle for greatest compression. This works to move the gases from the inlet into the foreline. It also works to keep the gas and oil molecules in the foreline from making their way to the inlet.

Pumping Speed

Turbo pumps typically operate at speeds ranging from 9,000 rpm to 90,000 rpm. For any given turbo pump, variations in the rotational speed will strongly affect the pumping performance.

The pumping speeds and compression ratios achieved with a turbo pump are related to the rotational speed. Unless a manual switch for "low-speed mode" is made by a user, full rotational speed is achieved at pressures lower than 1×10^{-3} torr (1 micron).

The pumping speed of the turbo pump is directly proportional to its rotational speed. For example, if a turbo pump has a rated speed of 300 ℓ/sec (normal rpm) and is switched to a "low-speed mode" that reduces rotational speed to 70% of normal, the turbo pump will pump at 70% × 300 ℓ/sec, or 210 ℓ/sec. The "low-speed mode" allows operation at pressures of several hundred millitorr. This is useful in applications such as sputtering, which require a gas backfill into the millitorr pressure range.

Most manufacturers of turbo pumps give pumping speed specifications for nitrogen, helium and hydrogen.

The pumping speed for a gas species is a function of the velocity ratio of the tip speed of the rotor blade to the thermal velocity of the molecule being pumped. Helium and hydrogen molecules have high thermal velocities, in excess of 1,000 meters/sec, compared with nitrogen molecules which move at approximately 450 meters/sec. This large difference in molecular thermal velocities is why separate pumping speed specifications are given for helium, hydrogen and nitrogen. For other air gases such as oxygen, argon and carbon dioxide, the pumping speed for a typical turbo pump is within 10% of the nitrogen specification.

Compression Ratio

The compression ratio of a turbo pump is equal to the foreline pressure divided by the inlet pressure for a particular gas species. It is an exponential function of the molecular weight of the gas and the rotational speed of a particular turbo pump. The major operational significance of the compression ratio of a turbo pump is that it determines the cleanliness of the vacuum system.

The compression ratio of a turbo pump is a function of the molecular weight of the gas being pumped. In a well-baked UHV system, the compression ratio for hydrogen will limit the ultimate pressure achieved in the system. This is because the residual gas in a baked-out system is typically over 85% hydrogen. The ultimate pressure (P_{ult}) is determined according to the formula:

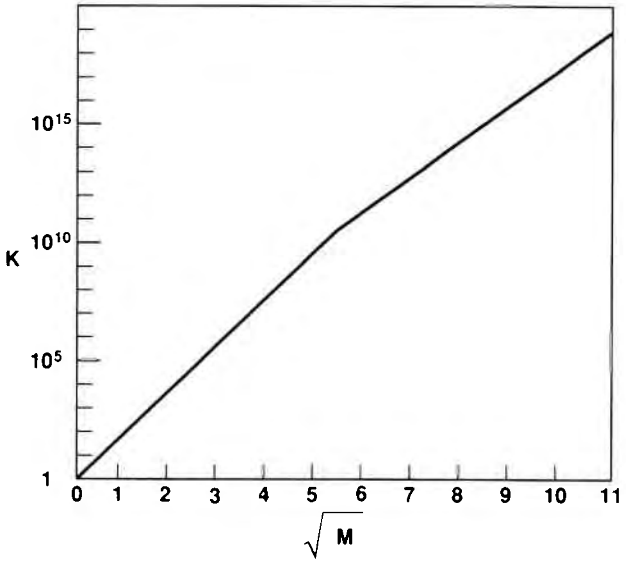
$$P_{ult} = \sum \frac{Q_i}{S_i} + \sum \frac{P_{2i}}{K_i}$$

where Q_i is gas load (for each gas species from outgassing),
S_i is pumping speed for each gas species,
K_i is compression ratio for each gas species,
P_{2i} is partial pressure at the exhaust for each gas species.

With an oil-sealed mechanical pump as the forepump, the foreline partial pressure of hydrogen is approximately 2–5 × 10^{-7} torr due to the hydrogen produced by cracking of the mechanical pump oil vapor. With typical turbo pumps having a compression ratio of 10^3 for hydrogen, the system pressure will contain a hydrogen partial pressure of 2×10^{-10} torr to 5×10^{-10} torr.

To obtain a lower ultimate pressure, into the 10^{-11} torr range, the turbo pump should be backed with another, smaller turbo pump which is then backed by a mechanical pump. This configuration is usually only used when the lowest possible hydrogen partial pressure must be achieved.

Mechanical pump oil typically has a molecular weight of at least 100. From the chart, the compression ratio, K, for this mass is 10^{15}.



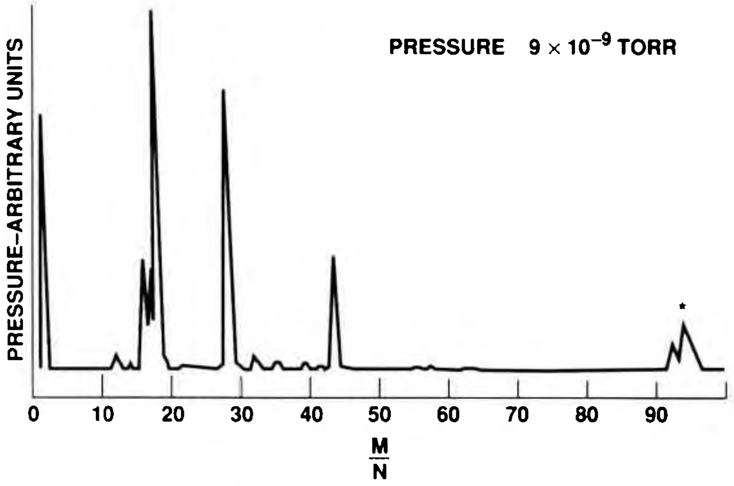
COMPRESSION RATIO (K) VS.
SQUARE ROOT OF THE MOLECULAR MASS

If the forepump is producing a foreline pressure of 1 mtorr (0.001 torr), then the partial pressure of hydrocarbon gas (mechanical pump oil) at the inlet of the pump is

$$= \frac{10^{-3}\,\text{torr}}{10^{15}}$$

$$= 10^{-18}\,\text{torr}$$

This is why turbo pumps produce virtually hydrocarbon-free vacuum. Only the most sensitive of analytical equipment can detect this level of hydrocarbon vapor.



MASS SPECTRUM OF UNBAKED TURBO PUMP SYSTEM

*RHENIUM PEAK (FROM FILAMENT IN RGA)

Pump Base Pressure

Ultimate or base pressure is defined as the lowest pressure measured in the standard test dome within 48 hours after the prescribed bakeout is finished, per international test procedures (DIN Norm #28428).

To achieve the lowest base pressure in a system then, it is necessary to bake out the system and the turbo pump. Many people accept the pressure reached without a bakeout as their base pressure.

Care must be taken to ensure the temperature of the turbo pump never exceeds the manufacturer's maximum allowable temperature at the inlet flange, typically 80°–120°C.

Most manufacturers supply heating mantles to give the turbo pump inlet a mild bakeout. The chamber can be baked out with strip heaters or a small clamshell oven.

Potential Problems

The most common failures of turbo pumps are due to particulates, lack of bearing lubrication, and shock.

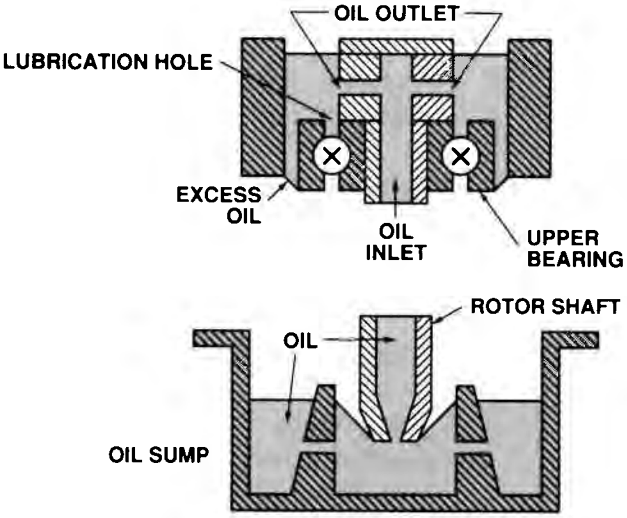
Lubricating Systems

There are a variety of methods used to deliver lubrication to the bearings. The most common are described below.

Circulating Oil

Oil is drawn up the shaft during operation and ejected over the bearings. This method provides a continuous flushing of the bearings, removing any particulates that have accumulated, and provides a continuous flow of lubricating oil. The oil also helps to cool the bearing.

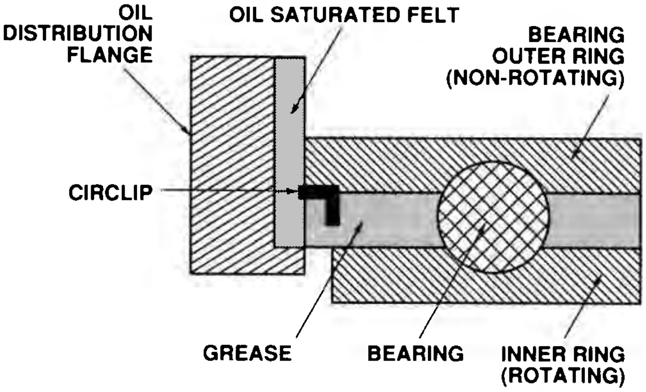
Circulating oil is the most reliable method of bearing lubrication; however, it requires a vertical mounting of the pump and water cooling. In addition to superior reliability, it allows a visible indication of the oil quality and quantity through a transparent oil sump.



OIL LUBRICATION OF TURBO PUMP BEARINGS

Grease-Lubricated Pumps
In this method, the bearings are packed in grease, which contains a lubricating oil. Periodically, oil must be injected into the pump lubrication port to replenish the consumed oil.

Advantages of this method are that the pumps can be mounted in any orientation and usually can be air-cooled. Disadvantages are that the status of the lubrication cannot be determined as with the oil-lubricated pumps.



VARIAN GREASE-LUBRICATED PUMP
OIL DISTRIBUTION DEVICE (SIDE VIEW)