The US Particle Accelerator School
Mechanical Vacuum Pumps

Lou Bertolini

Lawrence Livermore National Laboratory

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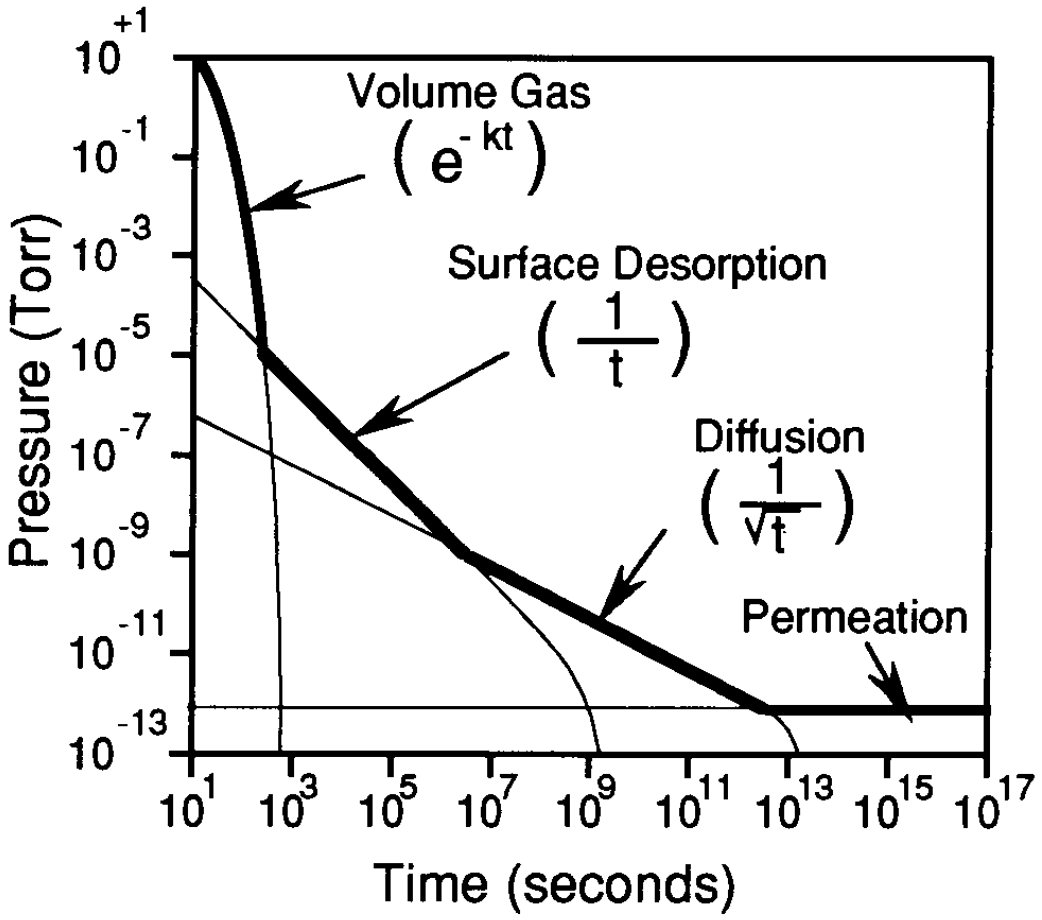
Mechanisms for Pumping

- Throughput mechanisms:
  - Positive displacement: **Molecules are compressed into a smaller volume, raising the pressure**
  - Momentum transfer: **Molecules are given a preferred direction by very fast moving surfaces or oil molecules**
- Capture mechanisms:
  - Chemical combination: **Molecules react with active metal surfaces and are converted to a solid**
  - Condensation: **Molecules land on a very cold surface and freeze into a solid**
  - Adsorption: **Molecules land on a surface and remain there**
  - Absorption: **Molecules land on a surface and dissolve into the bulk material**
  - Ionization & burial: **Molecules are ionized and accelerated into a surface with enough energy to burrow in**

Evacuation of a Vacuum System



Some Notable Characteristics of "dry" Pumps

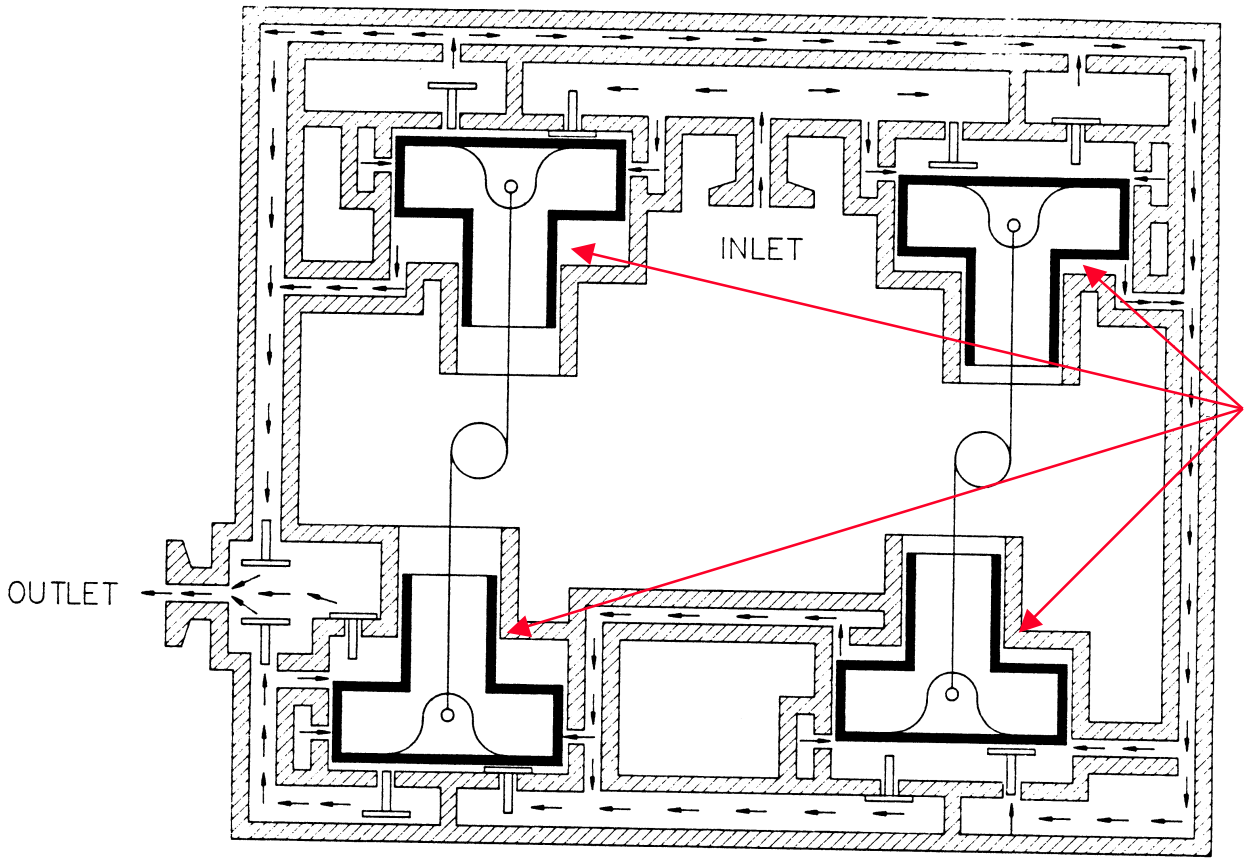
- Oil is often a contaminant in a vacuum system
- Destroys product, increases base pressure, affects sensors
- No oils are exposed to the gas stream
- Pump by positive displacement & momentum transfer
- Operating range 760 Torr to 10^{-2} Torr and lower
- Pumping speeds 2 to >150 CFM
- Lessens concern about malfunctions & trap integrity
- More compatible with corrosive gases than pumps requiring oil
- Expensive compared to oil based pumps ($3,000-$70,000)

"Dry" Pumps, Cont'd.

Several designs & configurations available:

- Multistage Roots
- Claw
- Multistage claw and Roots in series
- Scroll
- Screw
- Diaphragm
- Reciprocating piston
- Molecular drag & diaphragm pump in series

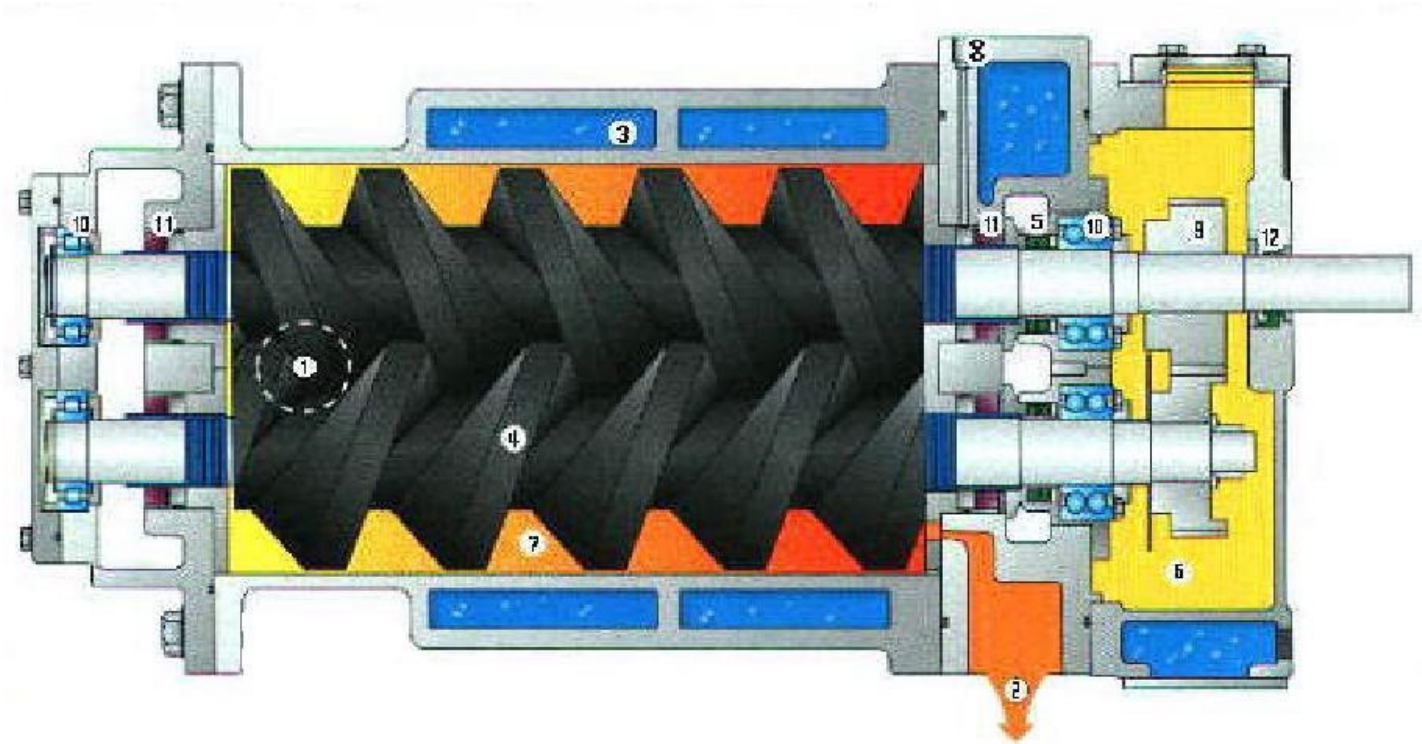
Reciprocating Piston Pump Cross-sectional Drawing



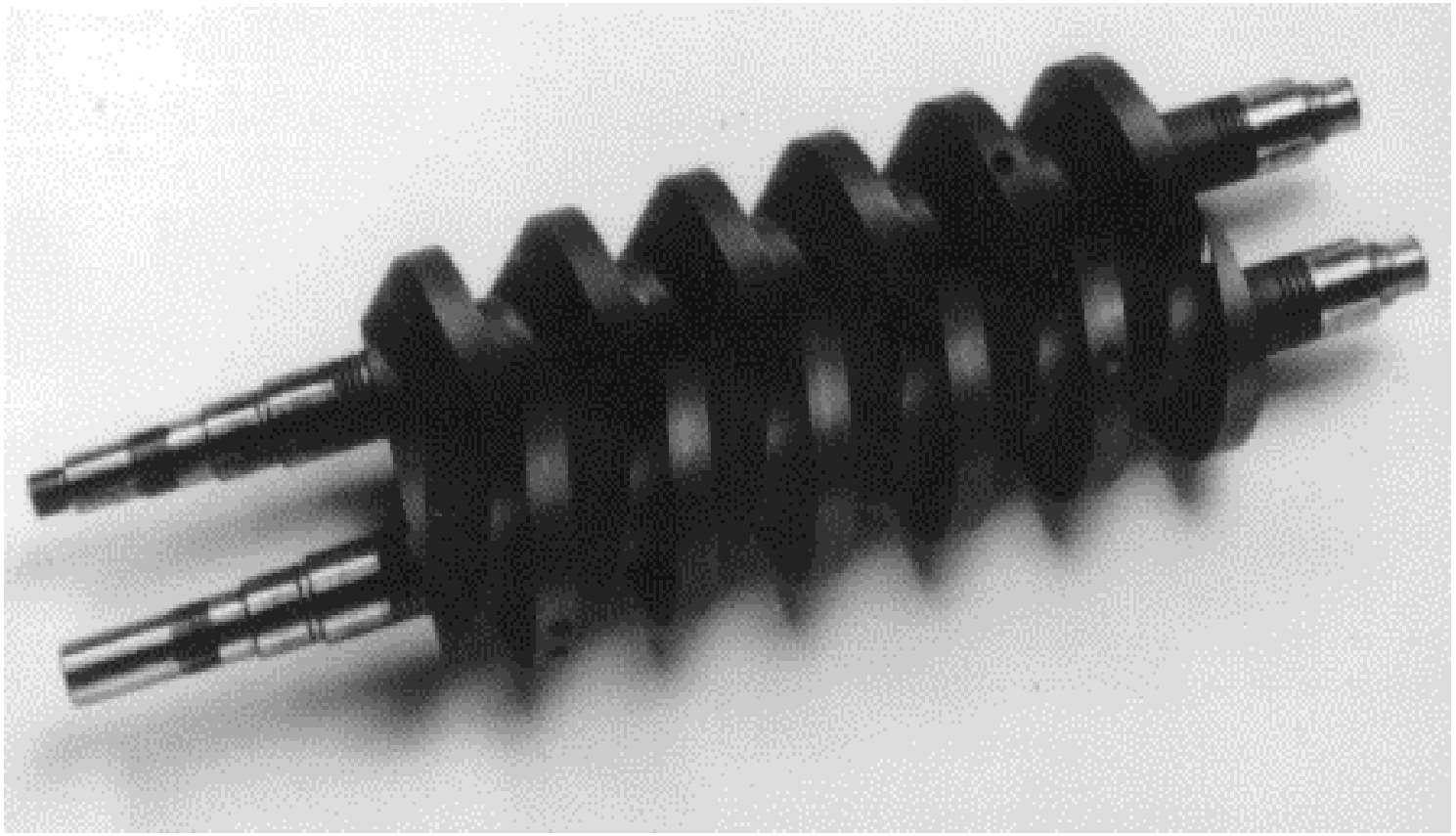
Varian first introduced their Piston "dry" pump in the late 1970's.

Diametrically-opposed Pistons are lined with Teflon.

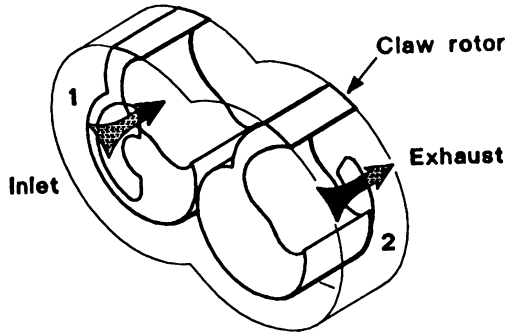
Busch Screw-type Dry Pump

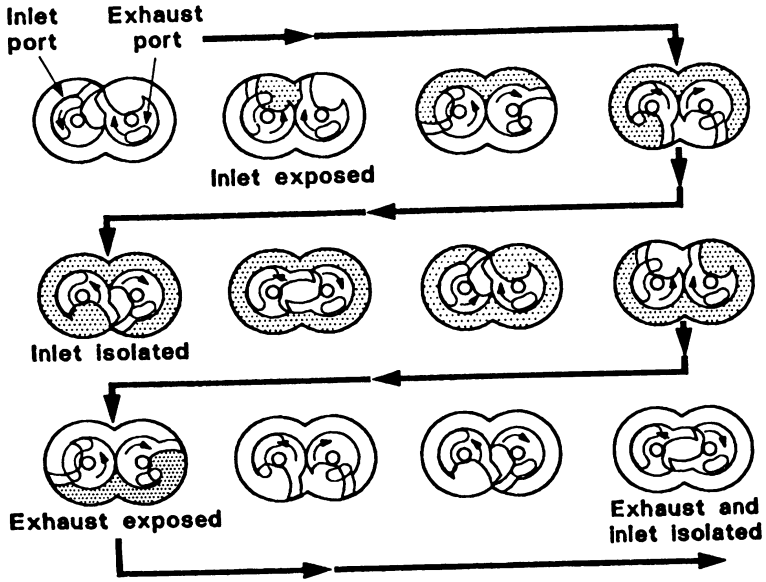


Photograph of Typical Screw Pump Rotors



Claw Mechanism and Operating Cycle

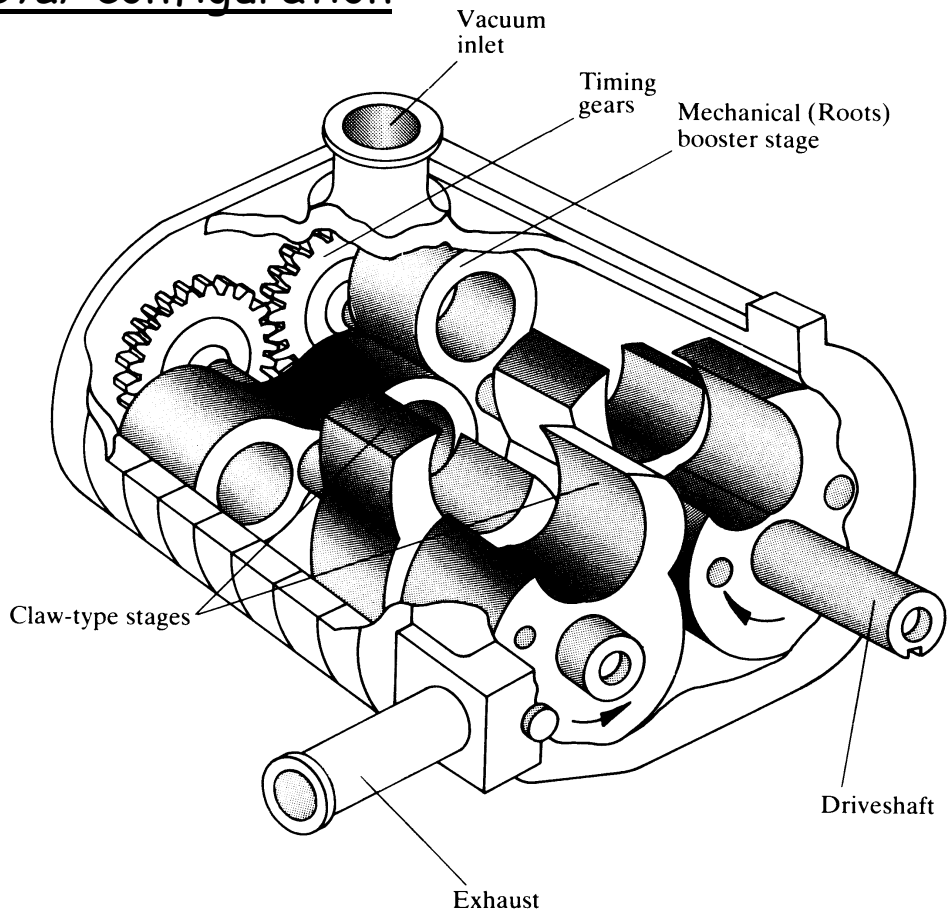




from "Foundations of Vacuum Science and Technology," Lafferty, 1998

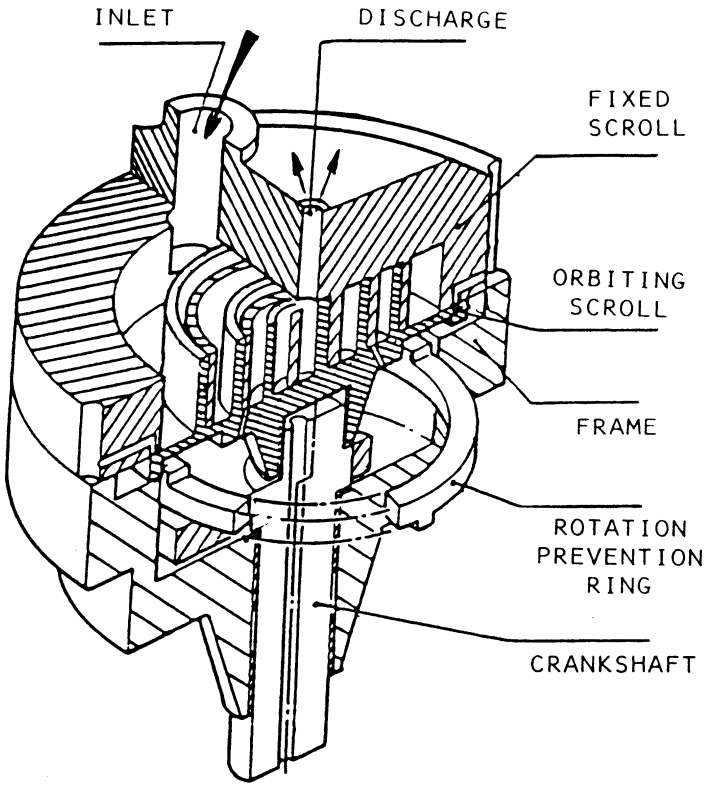
Multi-stage Roots and Claw in Series

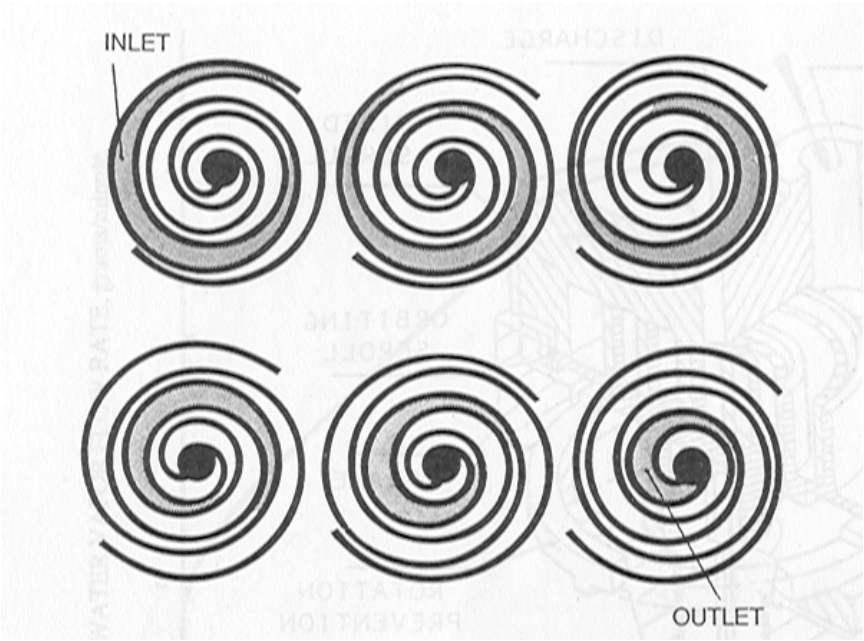
Edwards *Drystar* configuration



from Modern Vacuum Practice, Harris

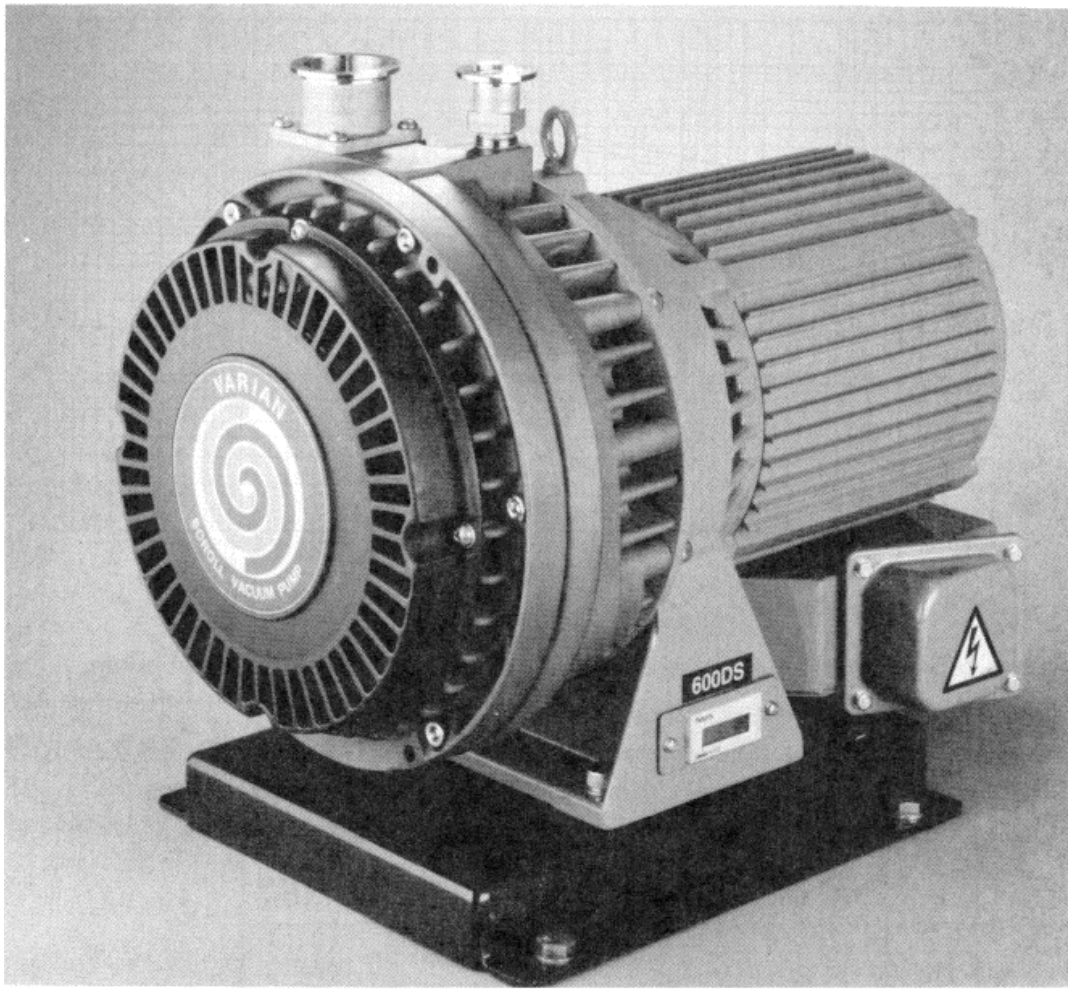
Scroll Pump Cut-away and Operation





from “High Vacuum Technology,” Hablanian, 1997

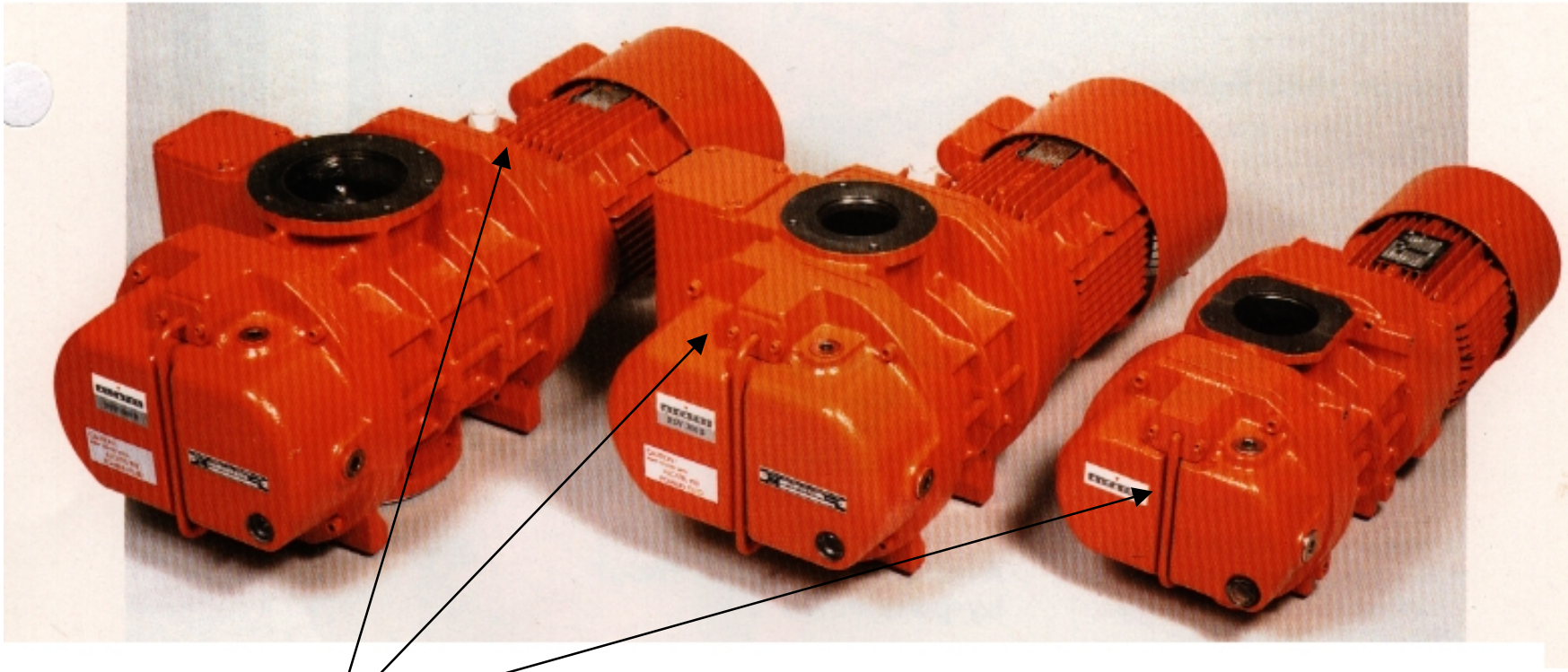
Photograph of a Typical Scroll Pump



courtesy of Varian Vacuum

Lobe-type (Roots) Vacuum Pumps

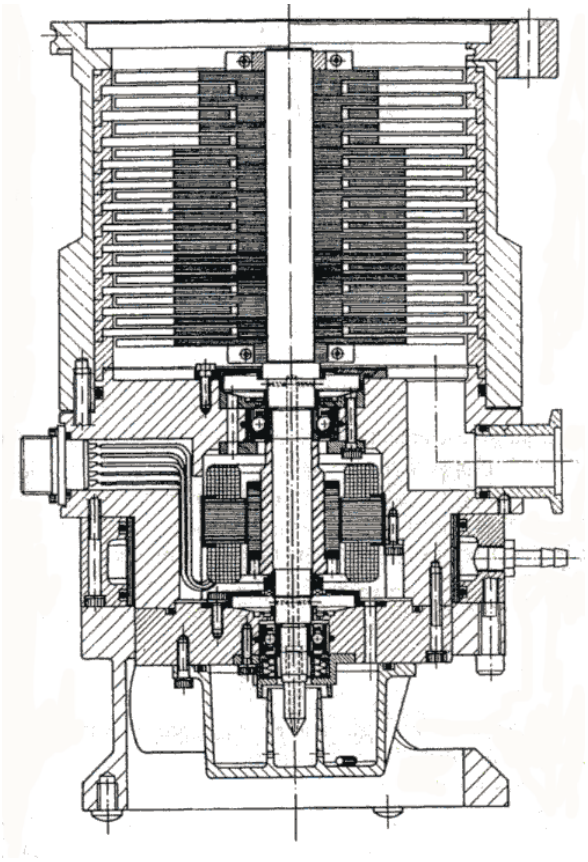
Many consider lobe-type pumps to be "dry". However, pump gearboxes contain oil!



Oily gearbox

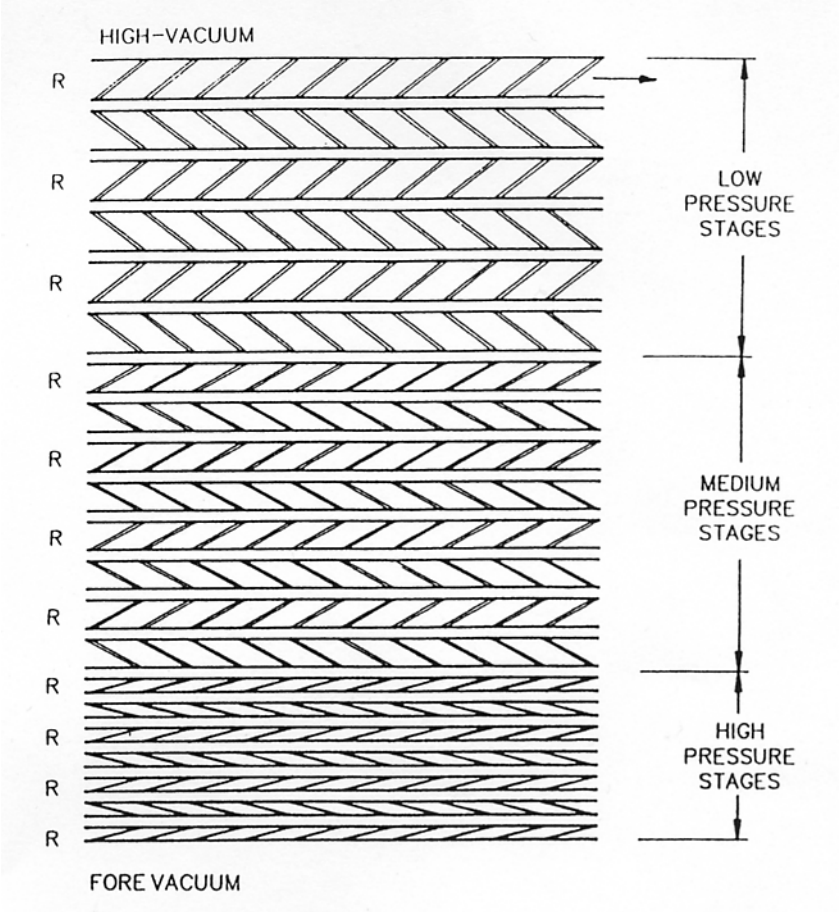
Turbomolecular Pumps

- Turbopumps are axial compressors designed for pumping gases in the molecular flow regime.
- Operating range 10^{-2} to 10^{-10} Torr
- Pumping speed 10 to 10,000 l/s
- Infinite pumping capacity
- Turbopumps are throughput pumps – meaning they have infinite capacity
- Blade rotation speed ranges from 14,000 to 90,000 rpm – making them mechanically vulnerable

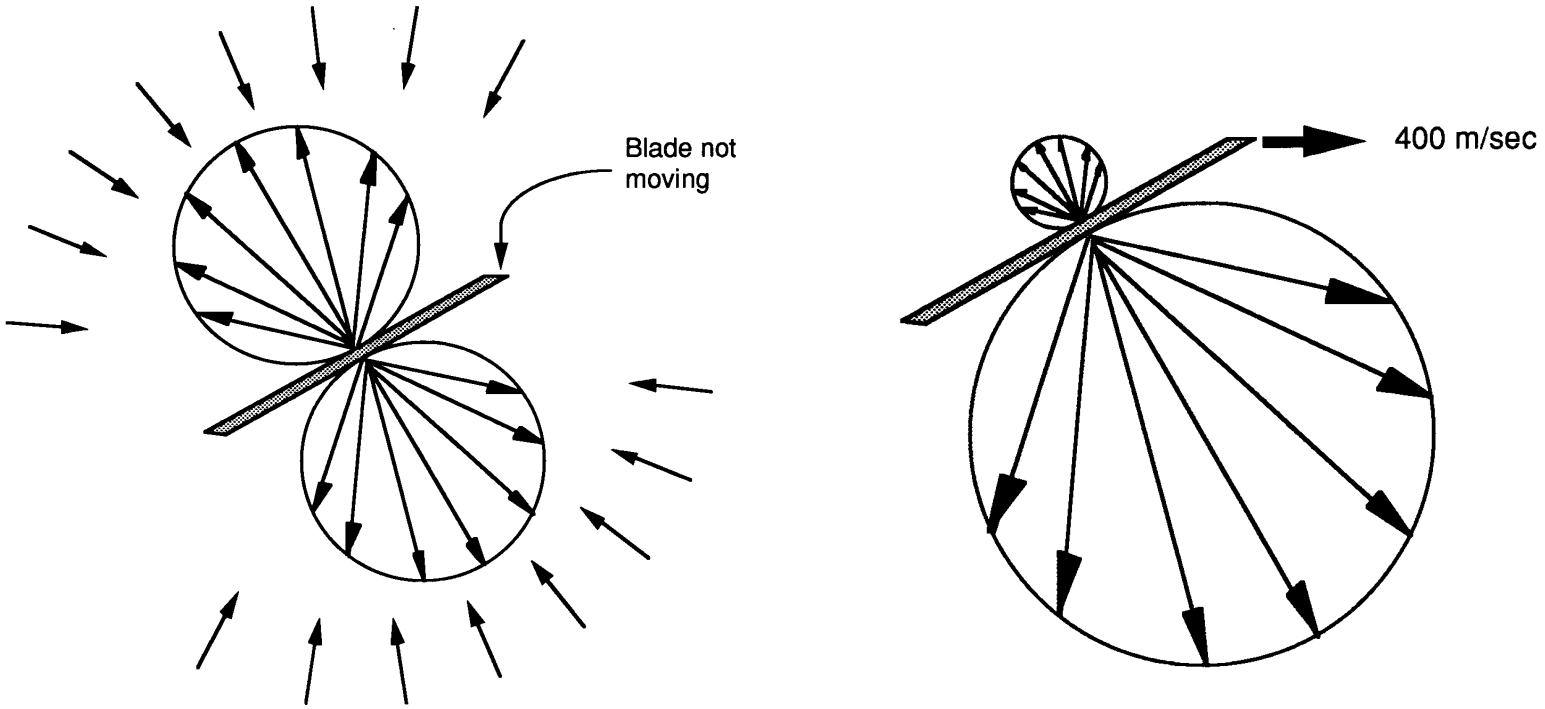


Turbomolecular Pumps, Cont'd.

- Axial compressor type pumps are very flexible designs:
  - # stages can be varied
  - Blade angles varied
  - Hybrid pumps
- Molecular flow exists through most of a turbopump; however, transient and sometimes viscous flow occurs at the pump discharge.
- The key parameter of turbopumps is compression ratio, not Δp.



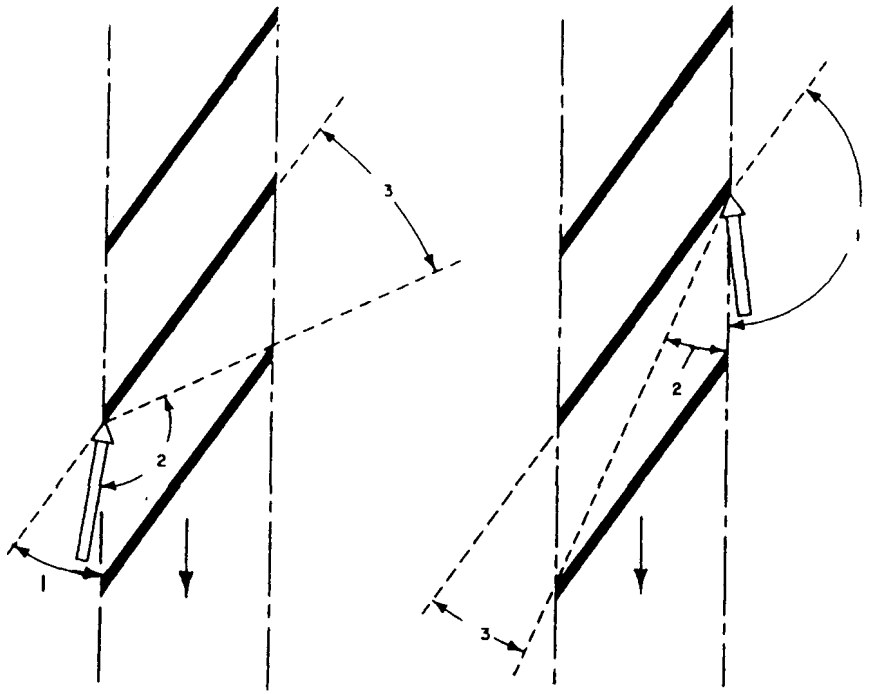
Rotating Turbomolecular Pump Blades accelerate gas molecules in a preferred direction.



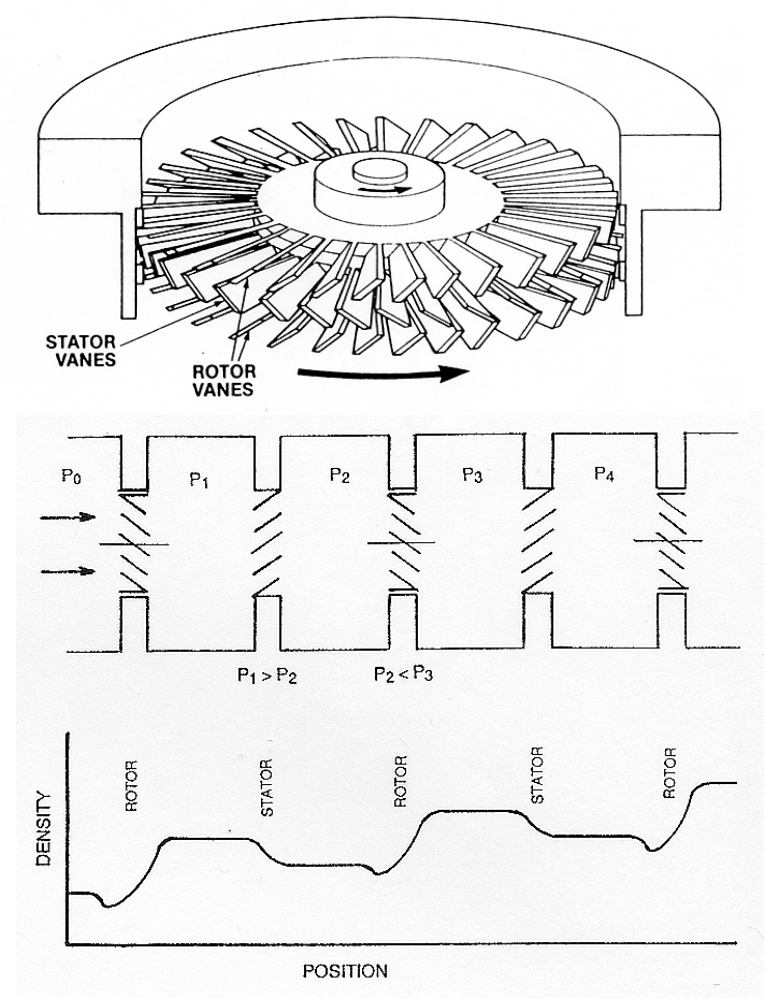
Velocity distribution from moving blades

Turbomolecular Pumping Mechanism

- Another way of looking at it, is to consider the rotors as moving "chevron baffles". Their relative movement gives the baffles a higher conductance in one direction over the other.
- Steep rotor blade angles produce higher conductances, which produces higher pumping speeds.
- Shallow rotor blade angles produce higher compression ratios.



Turbomolecular Pumping Mechanism

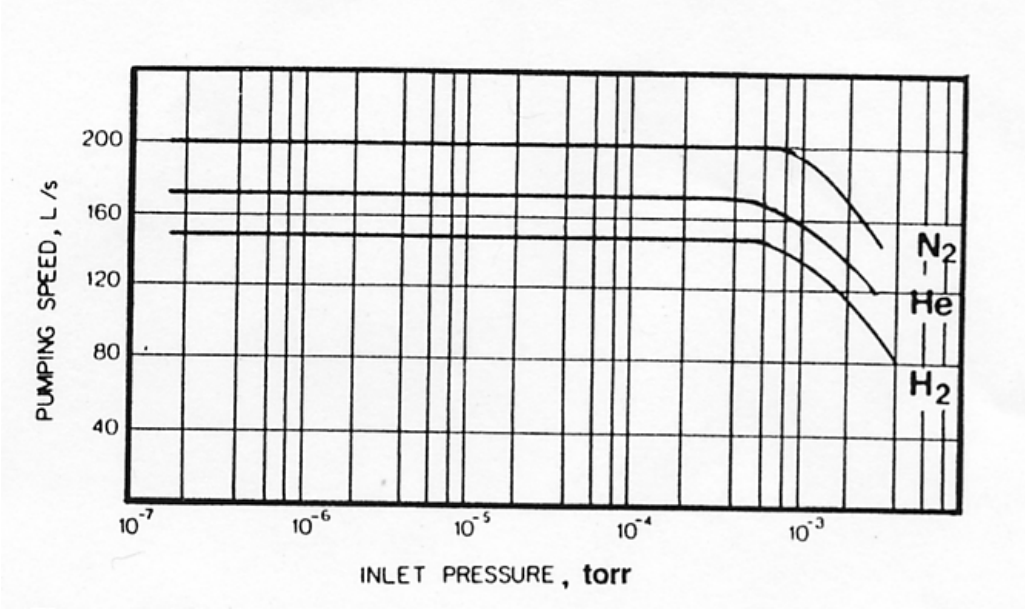


- The stator plays a complimentary role to the rotor.
  1. The stator slows slows down the gases and,
  2. Increases gas pressure without creating too much of a conductance limitation/
- The stator does it's job in as short a distance as possible.
- Rotors and stators are considered as a "pair" making up a "stage".

Turbomolecular speeds for different pumps

Pump parameters affecting speed:

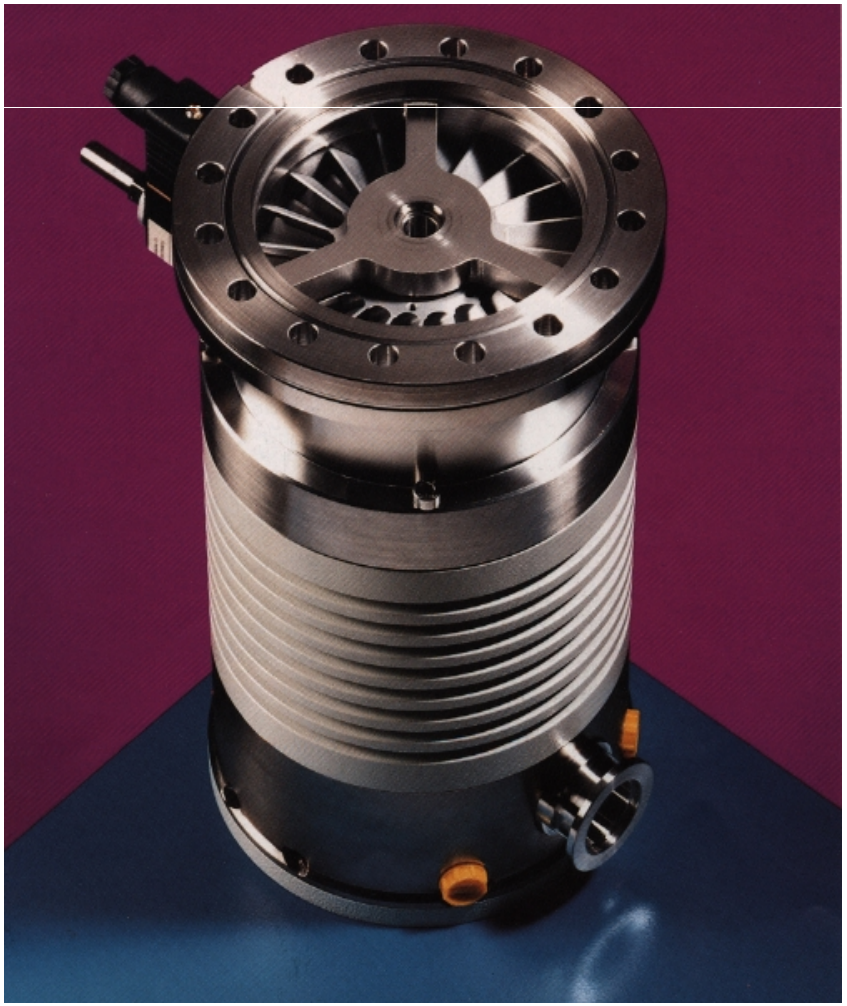
1. Rotor diameter and blade height (entrance area)
2. Rotational velocity of blades
3. Blade angle of initial rotor
4. Blade spacing ratio = $\frac{\text{distance between blades}}{\text{blade width}}$



Turbomolecular/Hybrid Pumps are Available in a Multitude of Sizes and Pumping Speeds

Courtesy: Varian Vacuum

Hybrid Pumps



Cut-away of a Typical Drag Pump