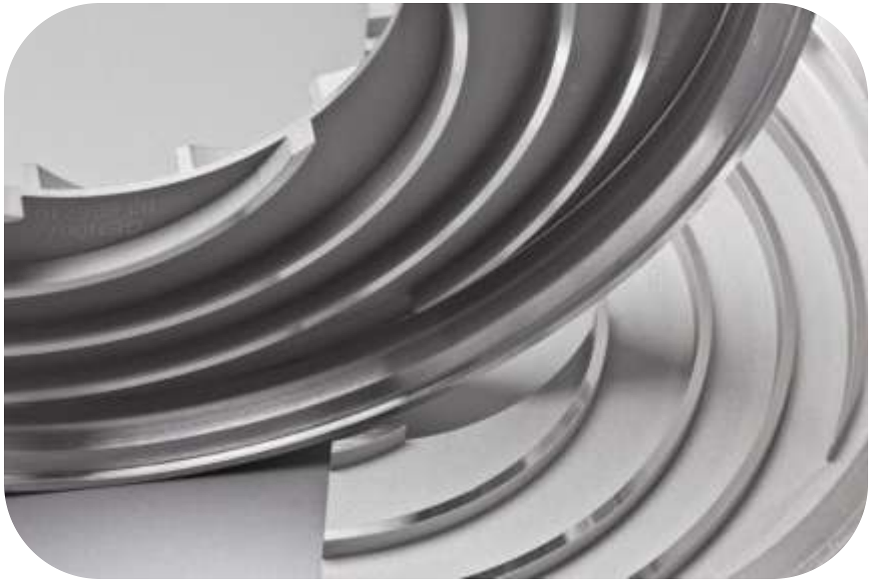
TwisTorr

The state of the art in Molecular-Drag Turbo-pump Technology



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Vacuum Products Division

Mauro Audi, Silvio Giors, Romina Gotta

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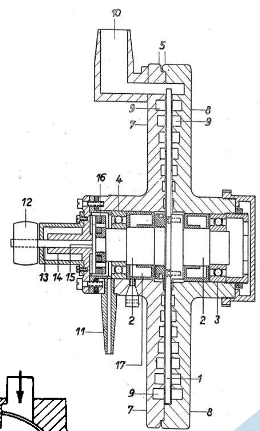
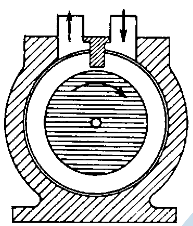
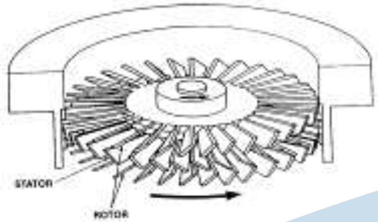
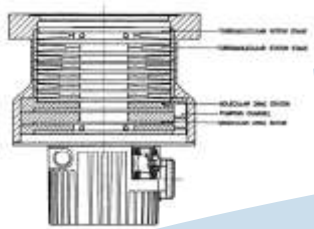
A contemporary history of innovation

Varian now a part of Agilent Technologies









Early 1900:

First Molecular Drag pumps

-1912 W.Gaede

-1922 F.Holweck

-1929 M.Siegbahn

1958:

First Turbo Molecular pumps :

-Double-Ended design (Becker)

-Axial flow principle (Hablanian).

-Double ended design was later abandoned

1960:

-Theoretical basis for pumping mechanism of axial flow impeller (Shapiro and Kruger, MIT)

1965:

-First prototype of axial flow turbo pump (Snecma), with thin bladed design

-This design is basis for modern TMP technology

1970:

-Snecma design Commercialized by Elettrorava, with manufacturing setup in Torino, Italy

1980:

-Introduction of ceramic ball bearing technology

-Compound Turbo Molecular Pumps appear, combining a Turbo section with a Drag section

1986:

-Varian starts collaboration with Elettrorava including technology and know-how transfer

1991:

-Varian introduces a new Hybrid type Turbo Molecular Pump: one monolythic rotor provides both high speed (Turbo stages) and high K-ratio (Macro-Torr® stages)

-Use of ceramic ball bearings lubricated for life using a proprietary dry solid lubricant

1996:

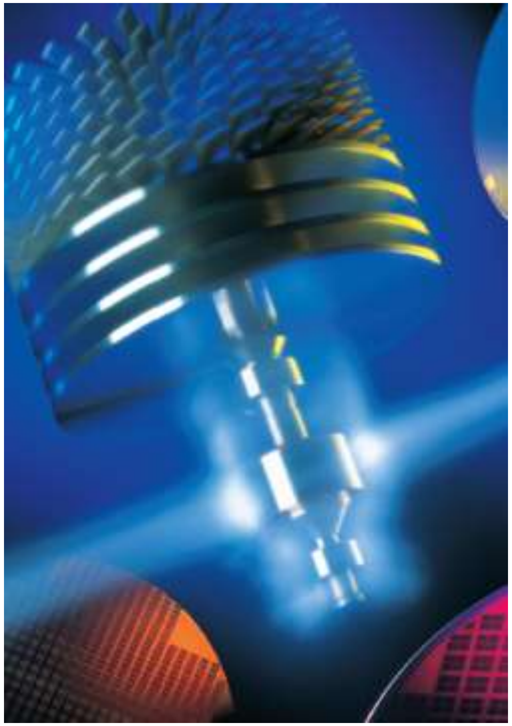
-Introduction of microprocessor based on-board controller units

2003:

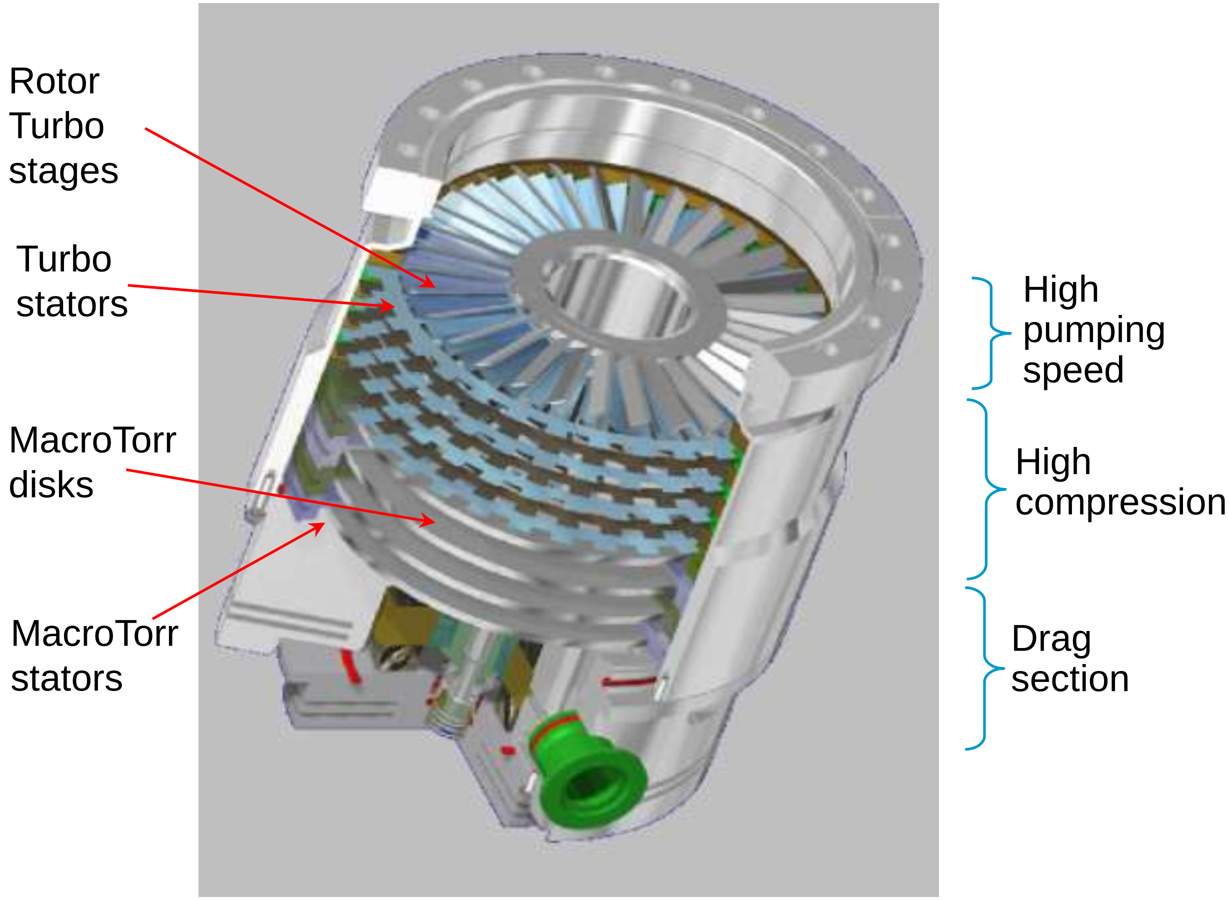
-Introduction of fully integrated Turbo pumping systems

2010

Turbo molelcular
Drag Pump Technology



Turbomolecular Drag pump



- Similar in design to a jet engine. Alternating rotor and stator blade
- Assemblies turn at 20,000-90,000 rpm to force out molecules.
- Turbo pumps cannot pump from atmosphere and cannot eject to atmosphere, so they require:
  - roughing pump to reduce the pressure in the vacuum system before they can be started
  - backing pumps to handle the exhaust

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Turbo section (1)
Working principle

Atoms and molecules hit against the fast moving surfaces of the rotor blades.

The rotor blades transfer momentum to the molecules in a preferred direction (downward). In order to be effective, the blades must move at a velocity comparable to the thermal speed of the gas molecules (Ex:@ 300-350 m/s - N2 thermal speed)

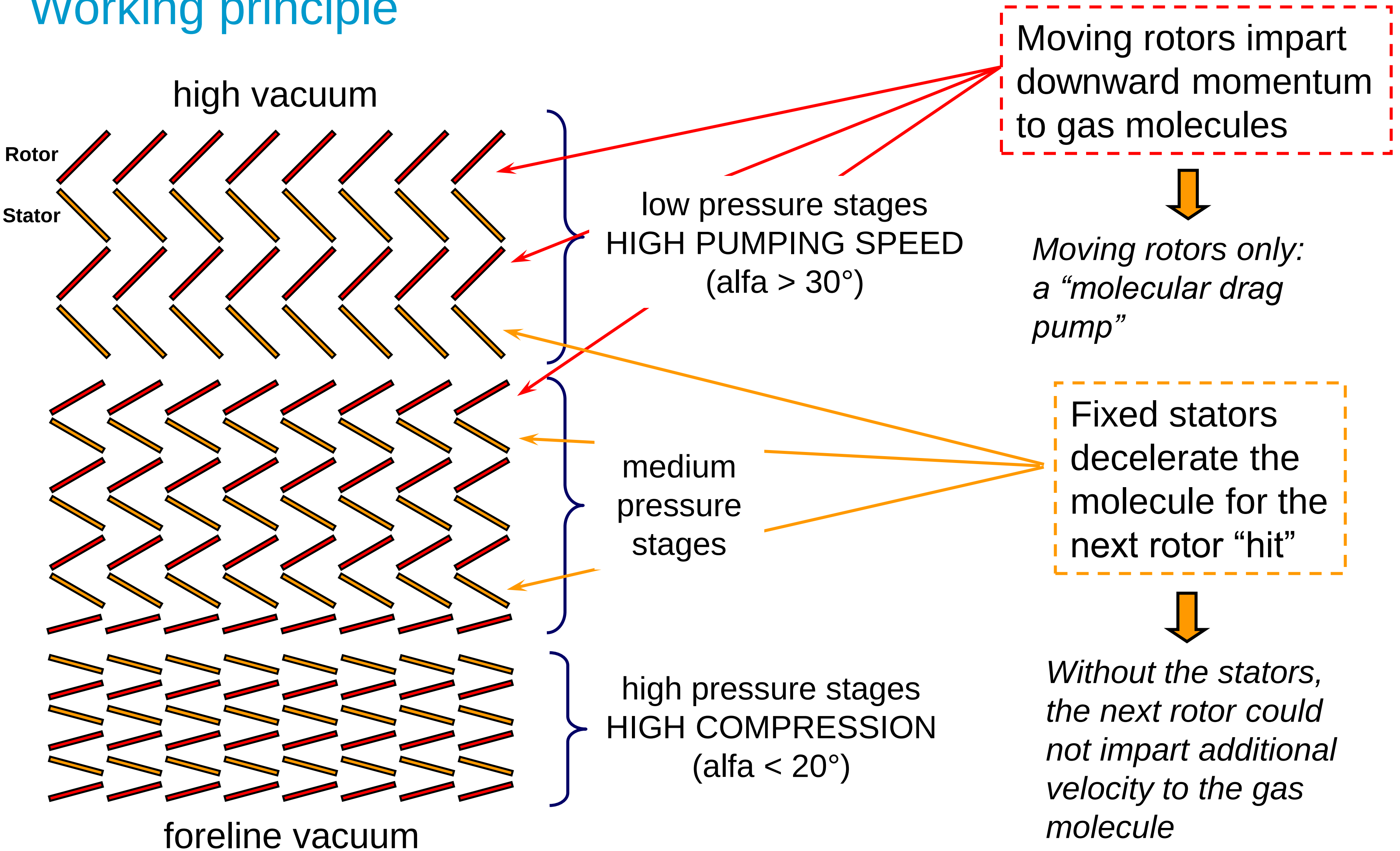
Pumping process: the non-directive motion of the particles is changed to a directive motion, hence creating a flow and a compression effect towards the pump outlet.

Designed to work in molecular flow conditions (*Kn*>>1), sometimes they operate in transition regime:

$$10^{-10} < p_{inlet} < 10^{-2} \text{ mbar}$$

$$10^{-3} < p_{foreline} < 10^{1} \text{ mbar}$$

Turbo section (2)
Working principle

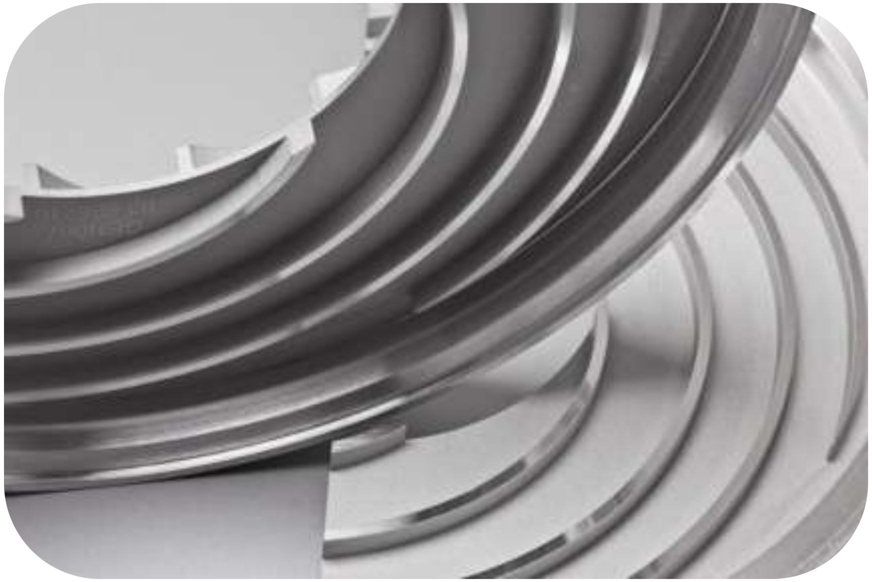


Turbo + Drag section
Combination pump advantages

The turbo molecular section provides:
A high pumping speed and a low ultimate pressure

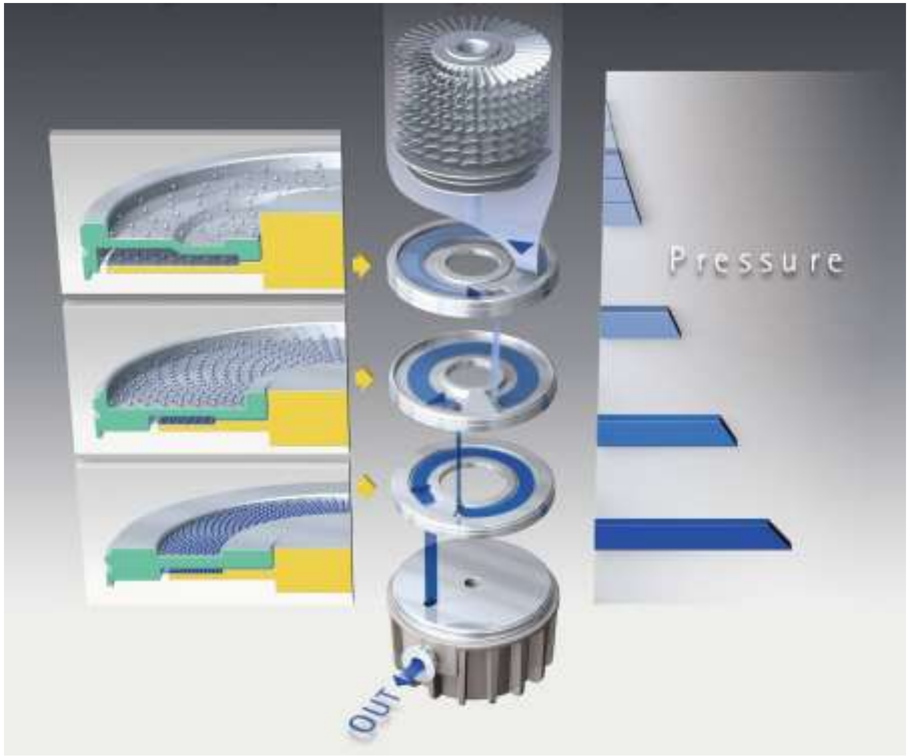
The molecular drag section provides:
- High Compression Ratio for light gases
- High Throughput capacity at pressure grater than 10^{-3} mbar
- Capability to handle high foreline pressure (10 mbar range)
  - *Use of small backing pumps*
  - *Lower Power consumption*

TwisTorr Technology Introduction

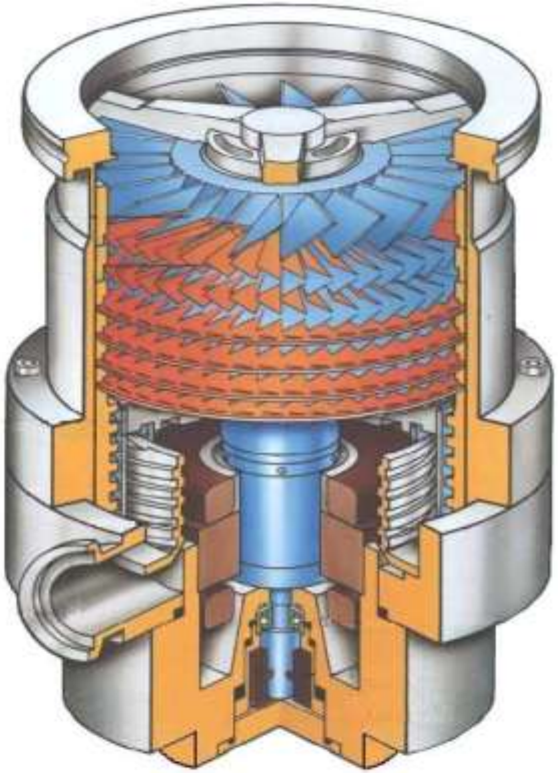


Introduction (1): turbomolecular-drag pumps

Molecular drag stages are used in turbo-drag TMPs to handle high foreline pressures (10 mbar range) and improve light gases compression→ allow smaller backing pumps and reach lower base pressures



Macrotorr® (Gaede pump re-designed) is Varian molecular drag TMDP design, with stages axially in series



Holweck molecular drag TMDP design (courtesy of Pfeiffer Vacuum), with stages in series nested radially

Drag section – The MacroTorr concept

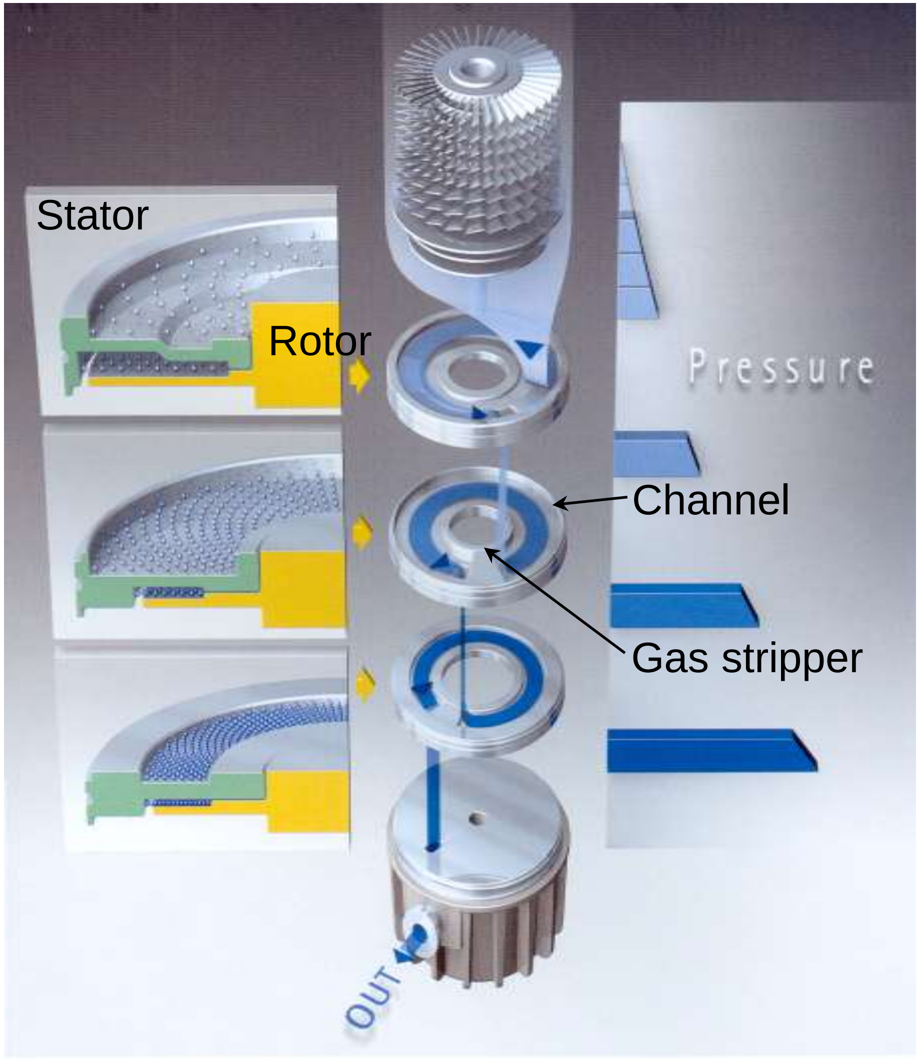
It is the original Varian patented technology for molecular drag stages

The molecular impellers consist of a disk rotating in a channel in which the inlet and outlet are divided by a stripper

Gas molecules gain momentum after each collision with the moving surface of the impellers

The gas is then forced to pass through a hole to the next stage due to the stripper

The cross section of channels decreases from the top to the bottom of the pump (from the low pressure to the high pressure zone)



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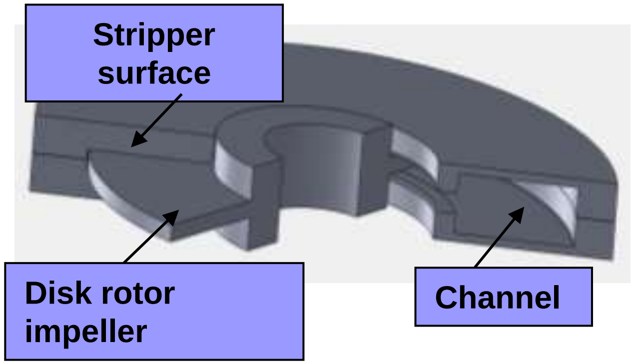
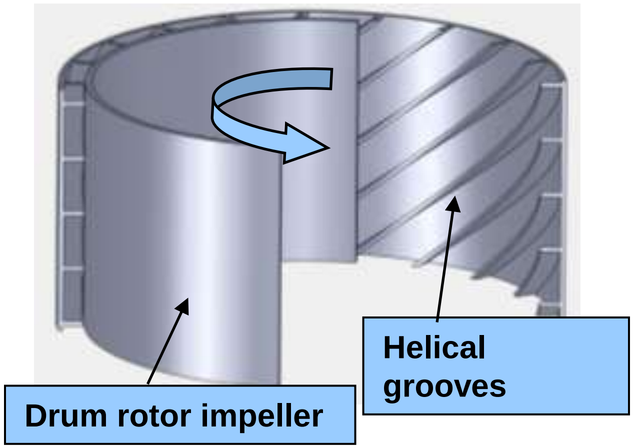
Introduction (2): molecular drag pumps designs

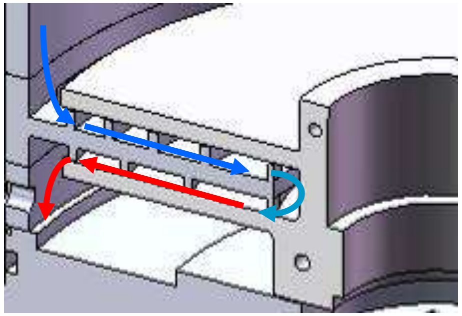
Macrotorr®



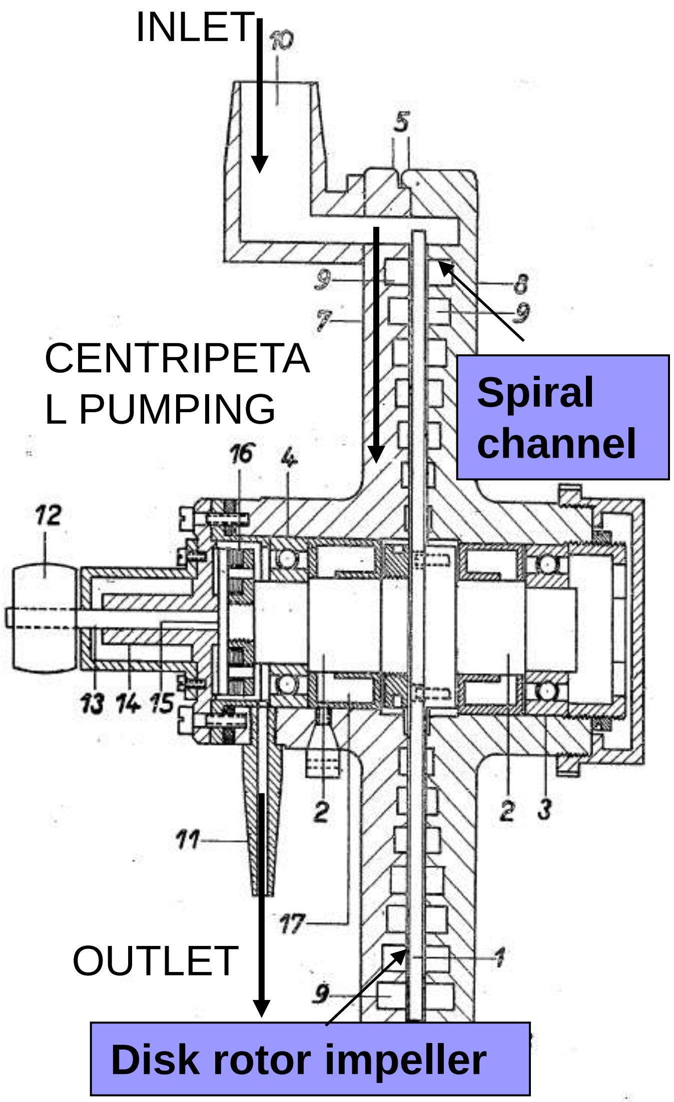
Holweck



Holweck stages are able to supply a high pumping speed, thanks to the presence of many channels in parallel and a high compression ratio, but this is obtained with the use of a less compact drum-shaped impeller, while Gaede stages are more compact but less performing and need more to get same performances.



TwisTorr introduction: Siegbahn molecular drag pump



Invention

Manne Siegbahn disclosed the spiral vacuum pump invention in GB patent No. 332,879 in 1929

Working principle

Molecular momentum transfer (“drag”, “friction”) pump, made of a smooth disk-shaped rotor with spiral grooves machined on a plane-geometry stator

- Same principle as Gaede and Howeck.
- Different geometry

Traditional design drawback

Tapered channels, with pumping speed not constant along in-series stages→ successive expansions and recompression waste power → **NEW TwisTorr DESIGN: spiral channels with <u>constant pumping speed S(r)</u>**

TwisTorr – Design

TwisTorr Invention (*):

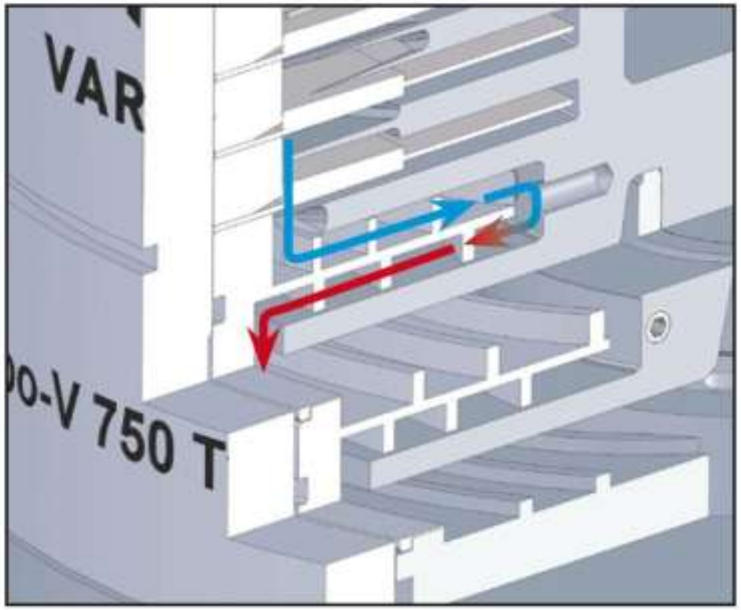
- Spiral grooves machined on a stator, cooperating with smooth rotating disks.
- Pump effect by momentum transfer to the gas.
- Stator spiral channel x-section area σ is increased from outer to inner radius, to compensate rotor velocity reduction at smaller radius and avoid reverse pressure gradients, minimizing power.

Rotor design:

- Each stator is positioned between two smooth disks (identical to Macrotorr® disks).
- Each disk is exploited twice in series (both surfaces).
- Fits well on standard Varian Macrotorr® design rotors

Stator arrangement:

- Stators with spiral grooves on **BOTH sides.**
- Centripetal **AND** Centrifugal combination in series to improve compression



(*) Patents applications 08-44 US, 08-45 US, by J.C. Helmer and S. Giors, Dec. 2008.

TwisTorr design: viscous model approach

Goal is to design spiral channels with constant S(r):

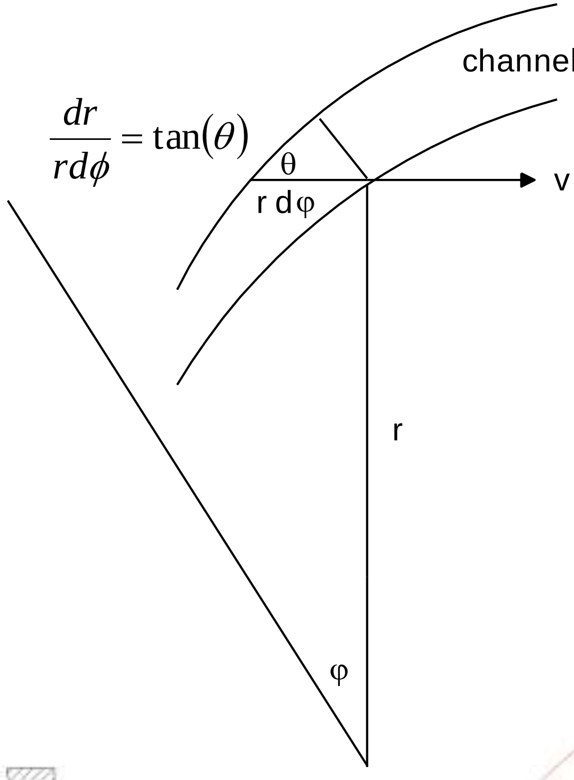
$$S(r) = \int h[\mathrm{v}\cos(\theta)][r\,d\varphi \sin(\theta)] = 2\pi\omega h \cdot r^2 \frac{\dfrac{dr}{rd\phi}}{1+\cancel{\left[\dfrac{dr}{rd\phi}\right]^2}},$$

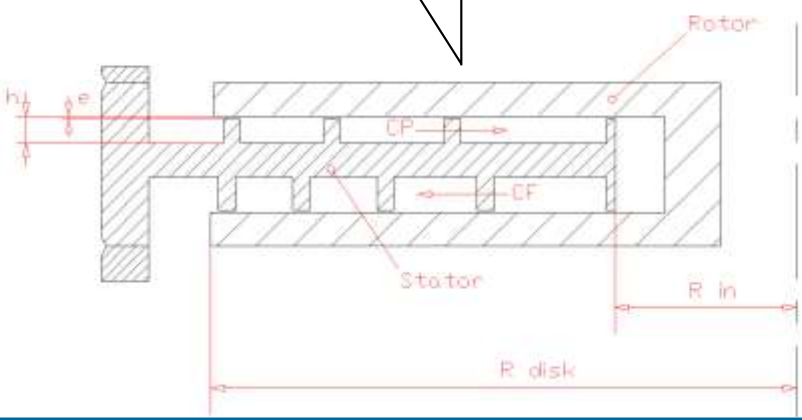
$$S = \pi\omega h \frac{rdr}{d\phi} = const \quad \Rightarrow \quad \boxed{\frac{r^2 - R_{in}^2}{R_{disc}^2 - R_{in}^2} = \frac{\phi}{\phi_0}}$$

$$S = \pi\omega h \frac{R_{disc}^2 - R_{in}^2}{2\phi_0}$$

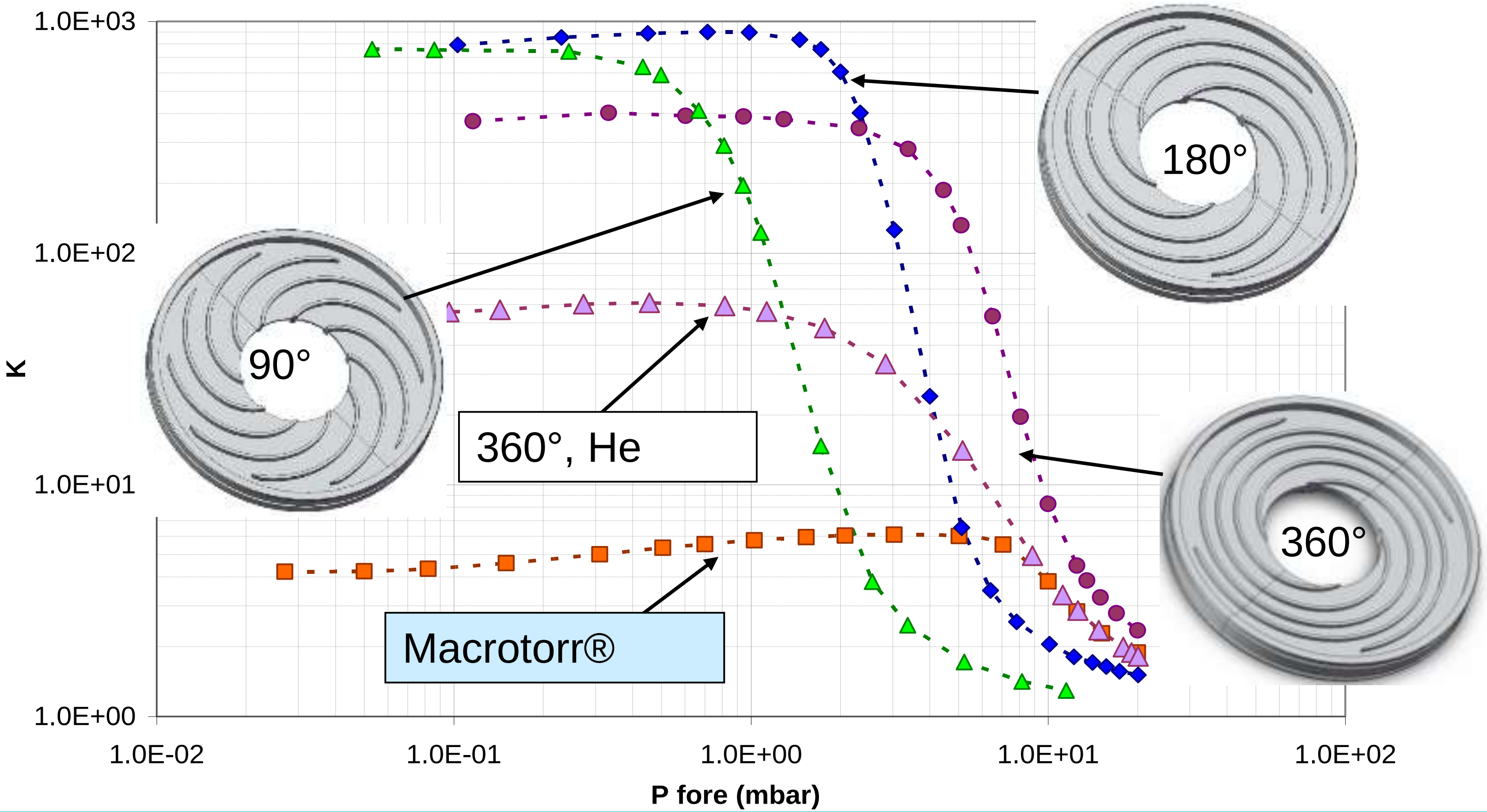
$$\Delta P \propto \mu \int \frac{\mathrm{v}r}{h^2} d\phi = \frac{\mu\omega\phi_o}{2h^2} \frac{R_{disc}^4 - R_{in}^4}{R_{disc}^2 - R_{in}^2} \approx \frac{\mu\omega\phi_o R_{disc}^2}{2h^2}$$

$$K \equiv (p_{out}/p_{in})_{\max} = ??$$



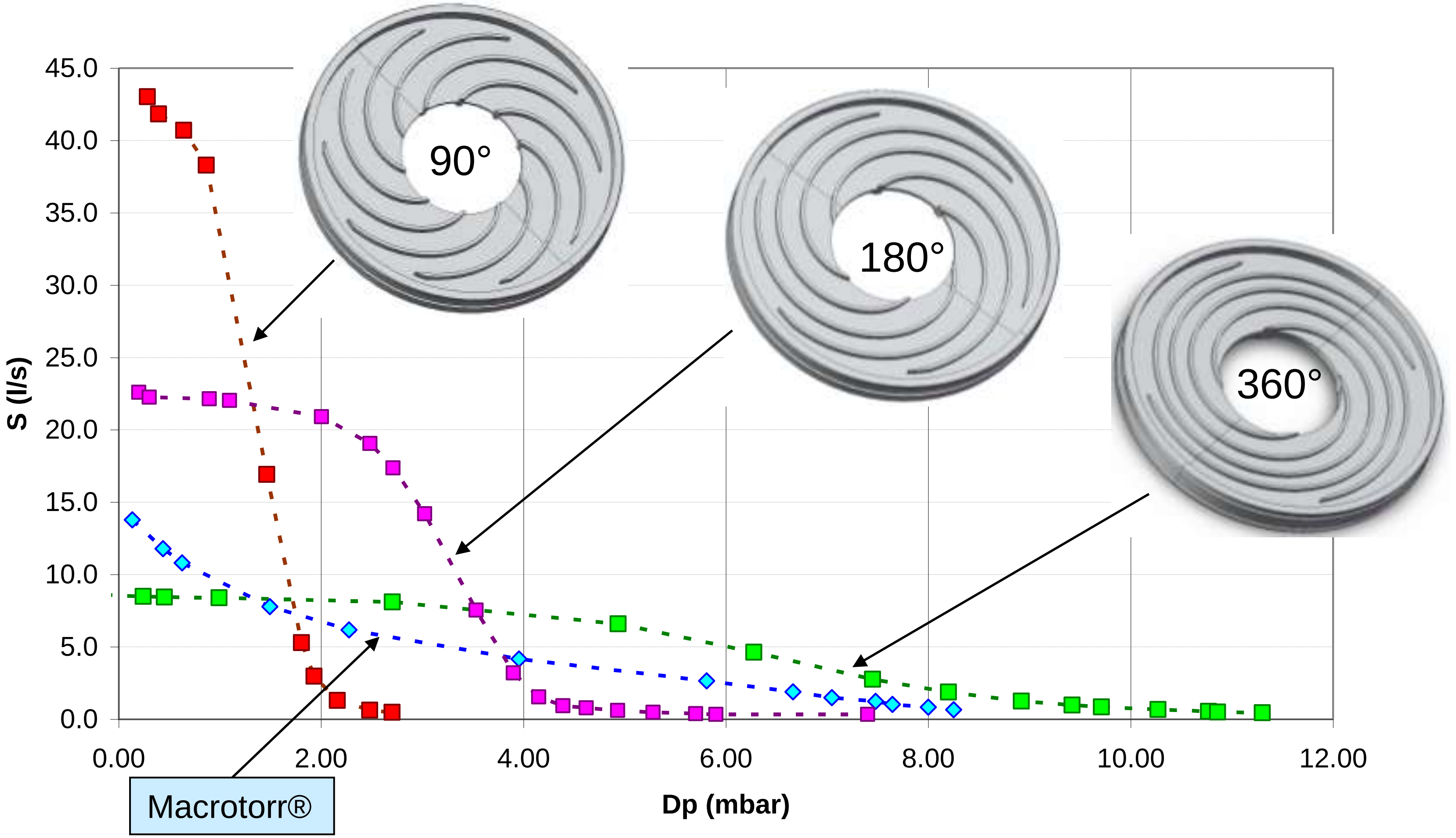


TwisTorr Advantages (1)



- TwisTorr increase Macrotorr N_2 compression by a factor 100.
- TwisTorr increase Macrotorr He and H_2 compression by a factor 10+.

TwisTorr Advantages (2)



N2 Pumping speed up to 5 times Macrotorr® can be obtained with an “open” 90° spiral design, which does not require to increase axial room as Macrotorr would do, and keeps a high compression ratio.

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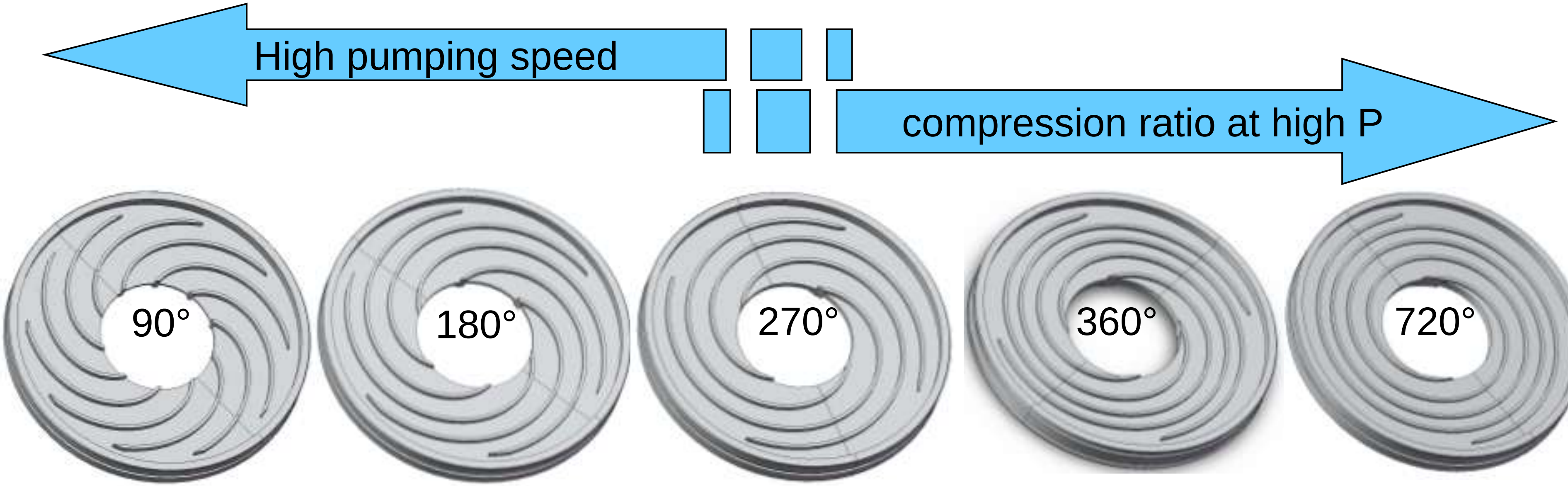
TwisTorr design possibilities



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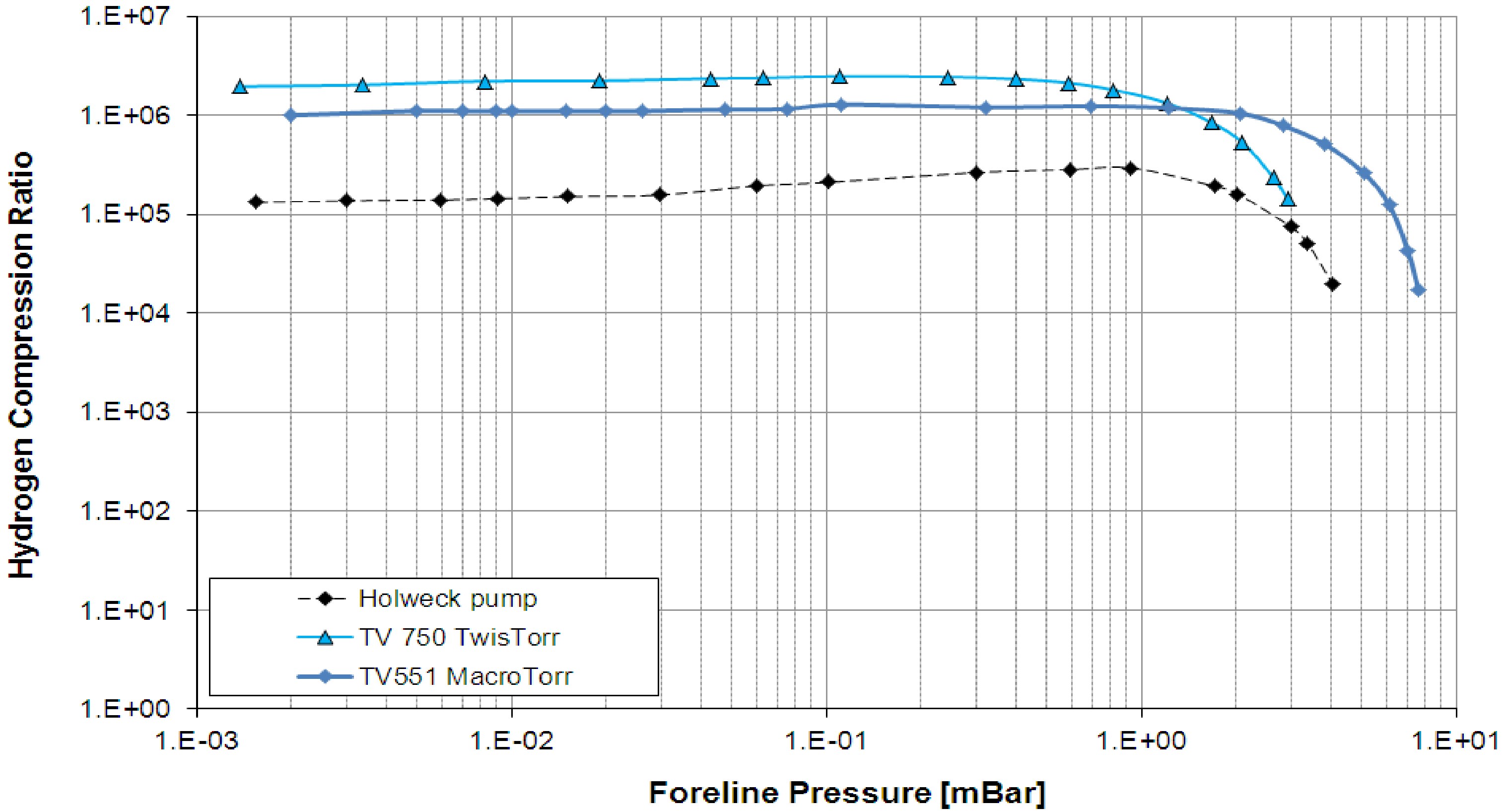
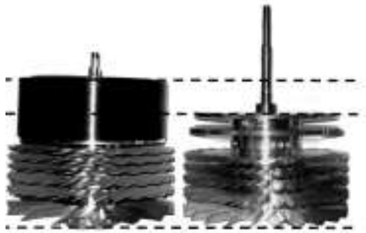
TMP Comparison with different drag stages: H_2 compression ratio



- TwisTorr based pump has a factor of 2 higher compression ratio for H_2 than the original MacroTorr based pump
- One order of magnitude higher K than Holweck pump, with a shorter rotor.



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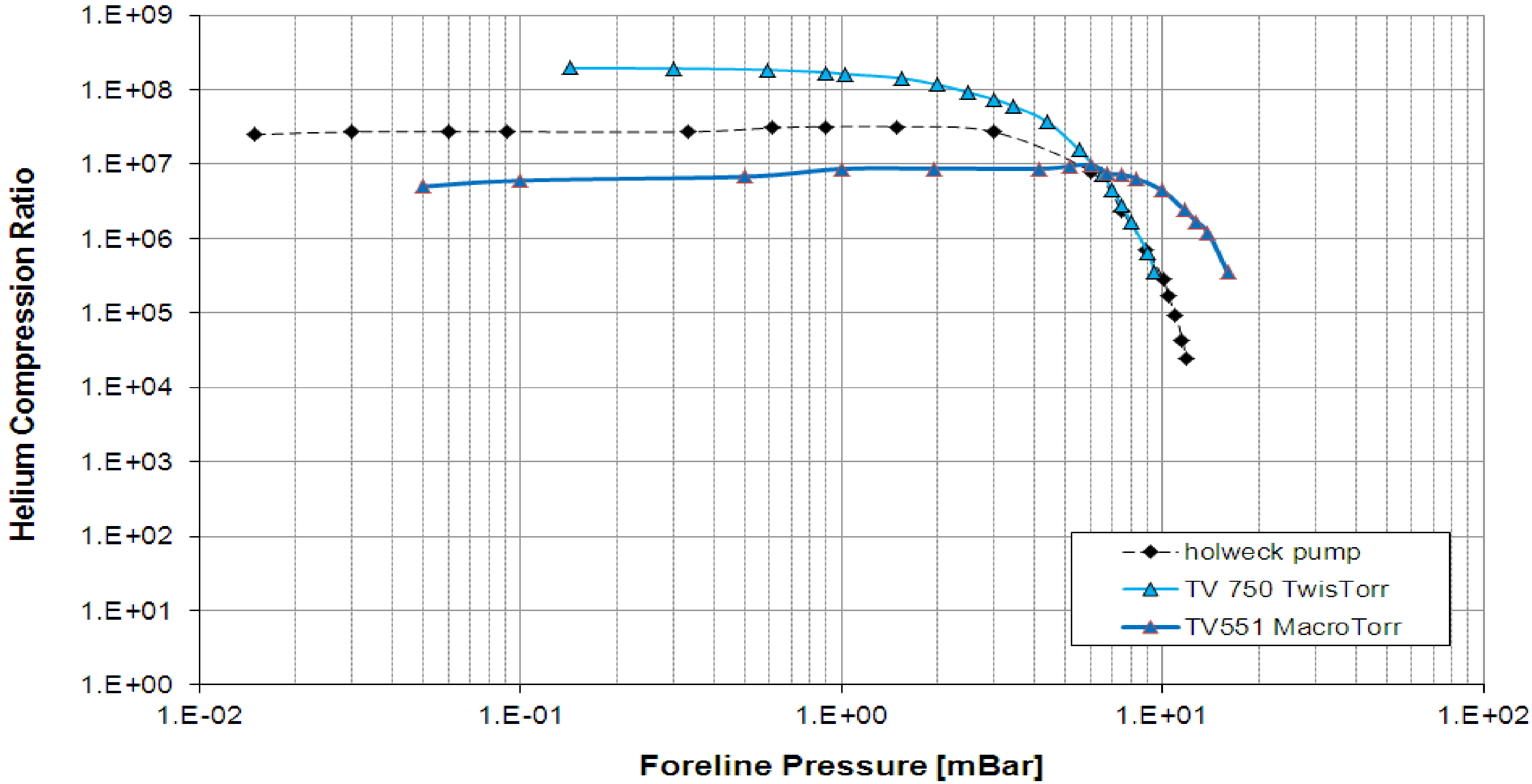
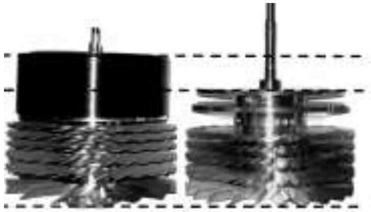
TMP Comparison with different drag stages: He compression ratio



- TwisTorr stages improve the original Macrotorr® compression ratio of a factor 20 for He.
- 5 times higher K than Holweck pump, with a shorter rotor.



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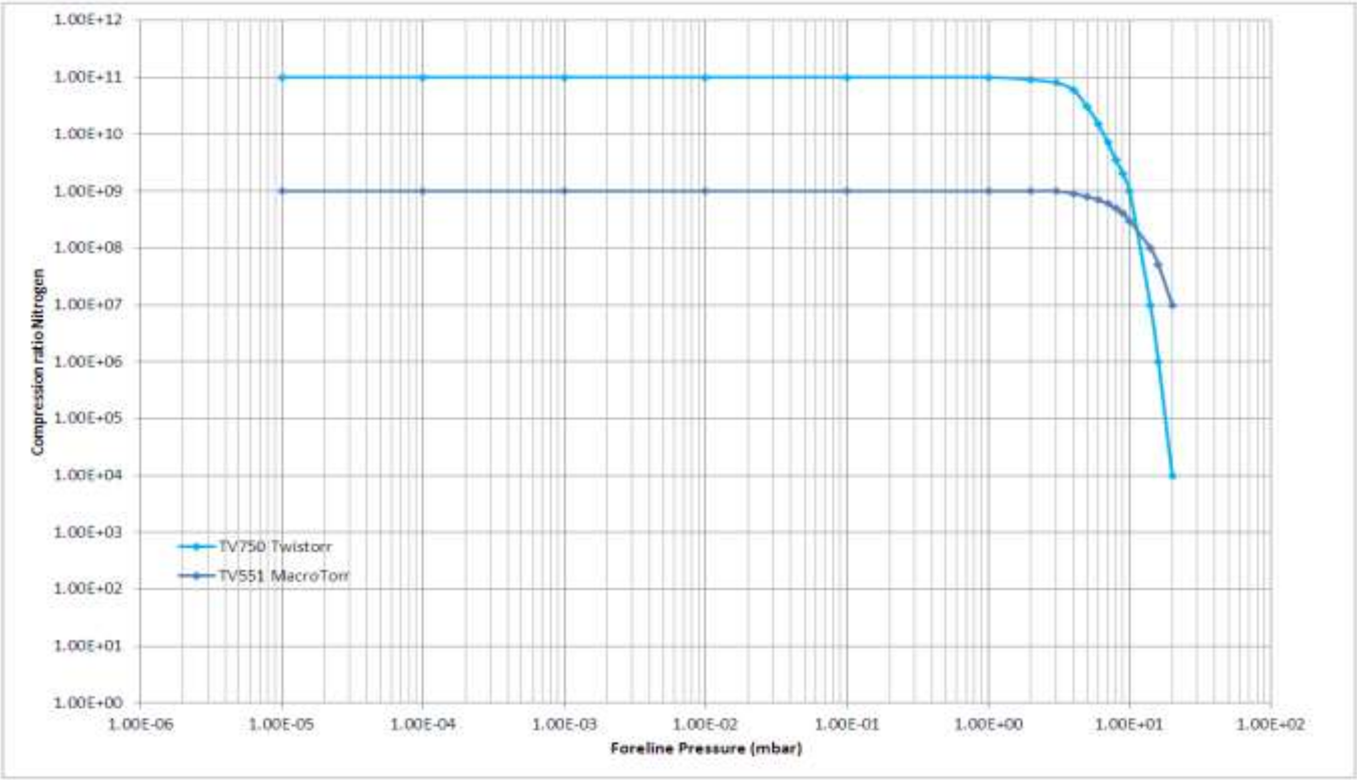
TMP Comparison with different drag stages: Nitrogen compression ratio



- TwisTorr stages improve the original Macrotorr® compression ratio of more than two decades for N_2
- Better perfomances than Holweck pump, with a shorter rotor (not shown).

Conclusions and perspectives

- A novel spiral molecular drag stage design with constant pumping speed has been developed, with the advantages of both high compression ratio and pumping speed per stage and very compact design.

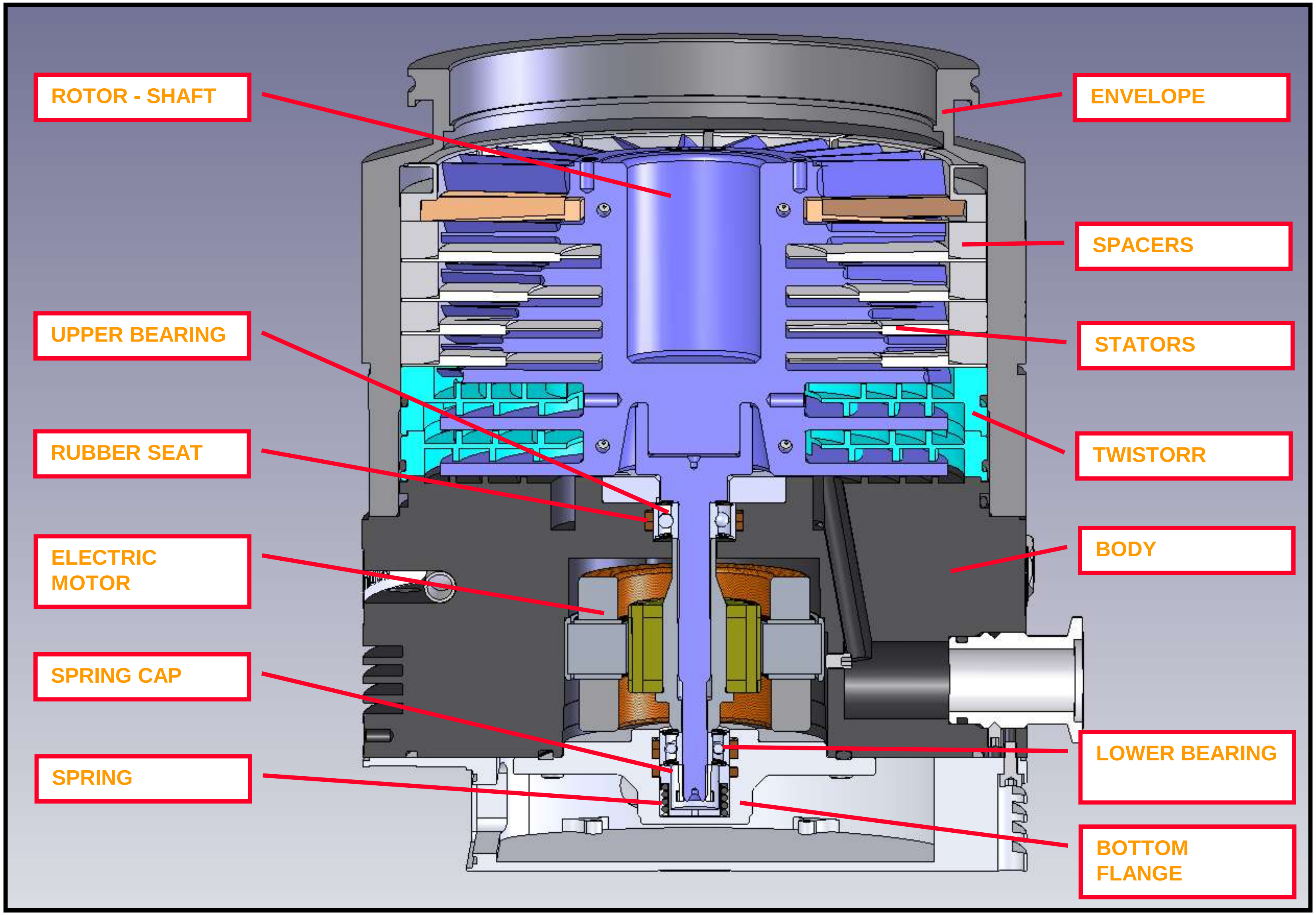
- A stage occupying the same axial room of the Macrotorr, could supply the same compression ratio and pumping speed of a Holweck stages in a smaller axial room.

→The comparison with existing Macrotorr and Holweck based 700 l/s pumps, showed the advantages of the new design.

→V551 MacroTorr 273 mm (334 mm with on board controller)

→V750 TwisTorr 252 mm (264 mm with on board controller)

Turbo-V 750 TwisTorr



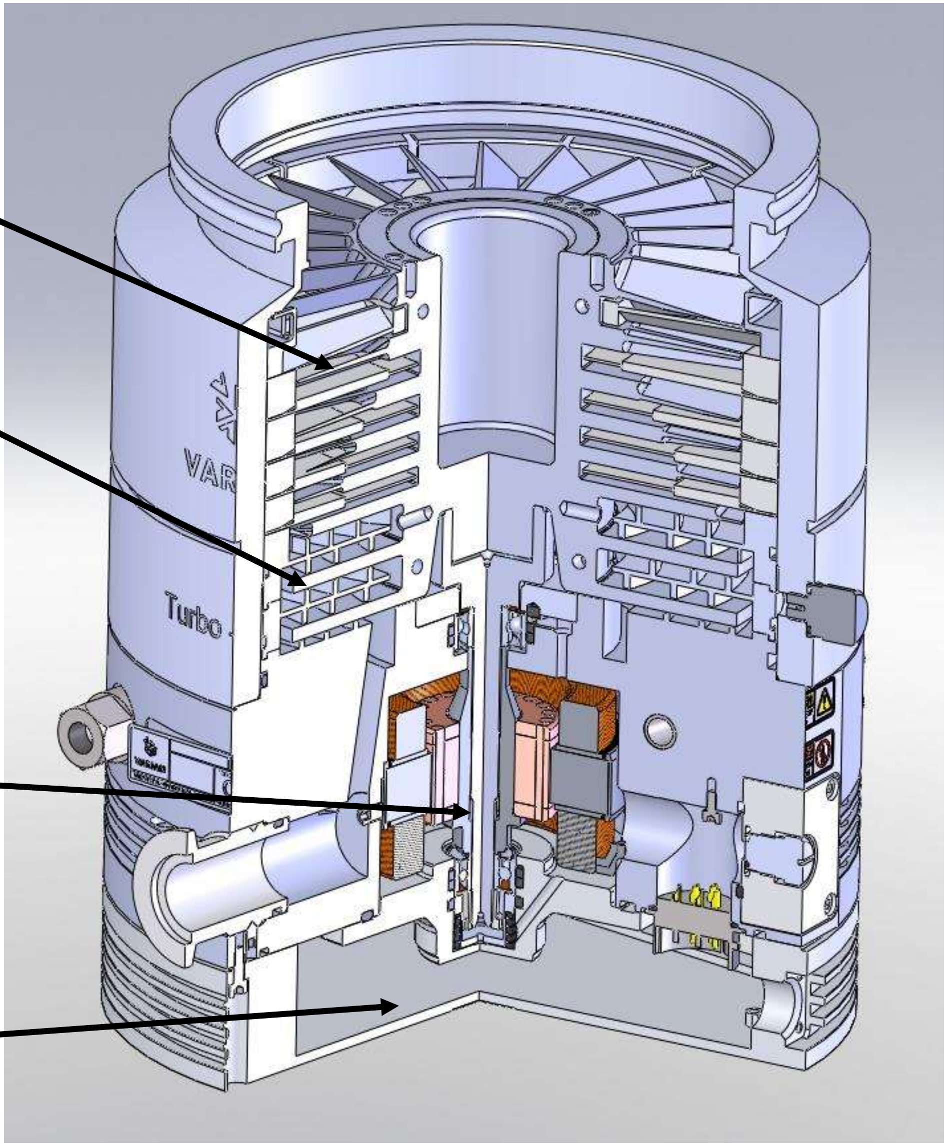
New Turbo-V 750/850 TwisTorr

Turbomolecular section:
5 turbo stages vs. the 8 Turbo stages of the TV551

Drag section with the new Twistorr Technology:
N. 2 ½ TwisTorr stages vs 4 Macrotorr stages of the TV551.

New bearings suspension:
- Inverted shaft fitting (Patent Pending)
- New bore-10 bearings

IP54 On-board control unit:
- 48 Vac electrical motor
- New Field oriented control to replace the current V/f control
- 20% shorter ramp-up time



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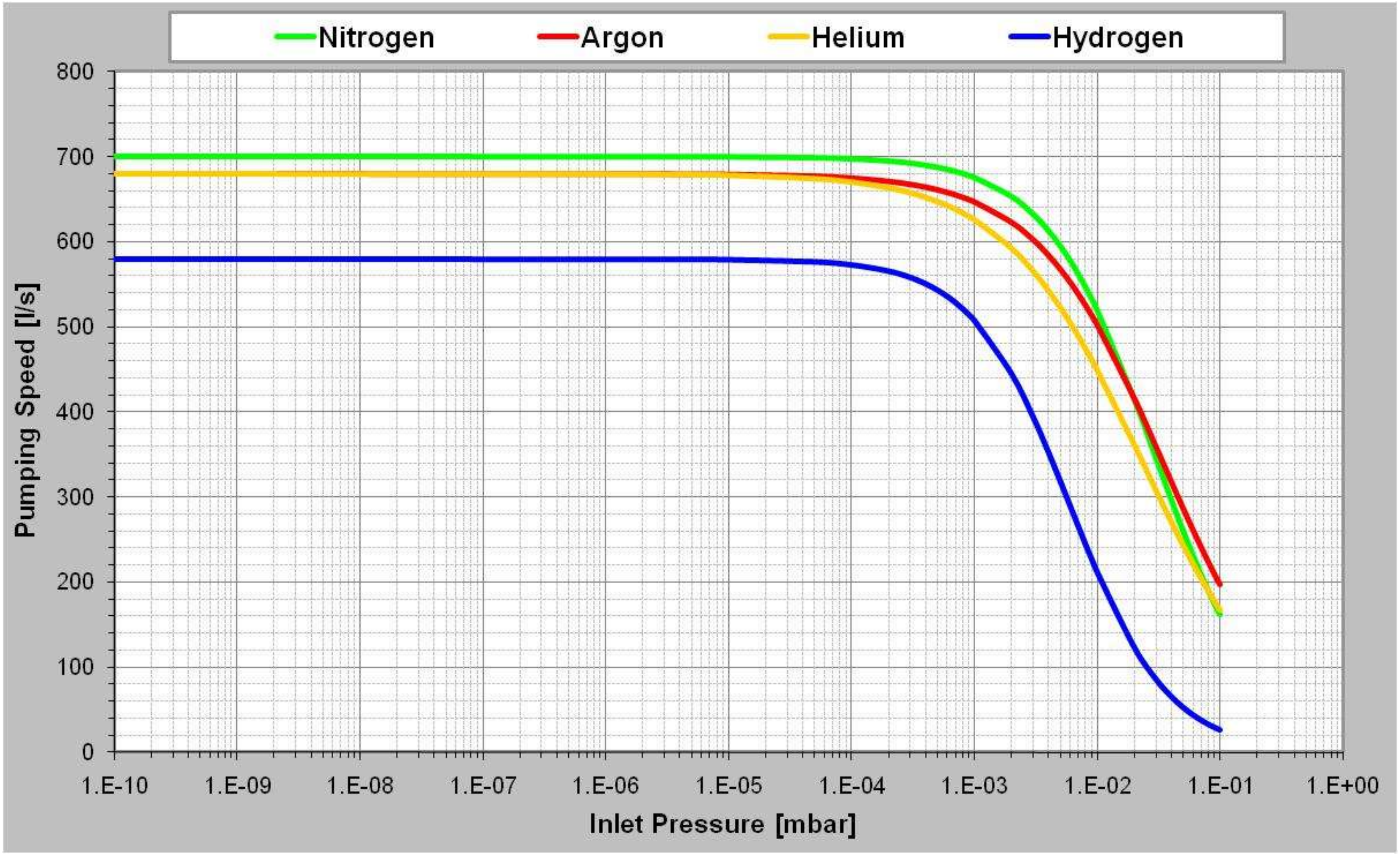
New Turbo-V 750 TwisTorr

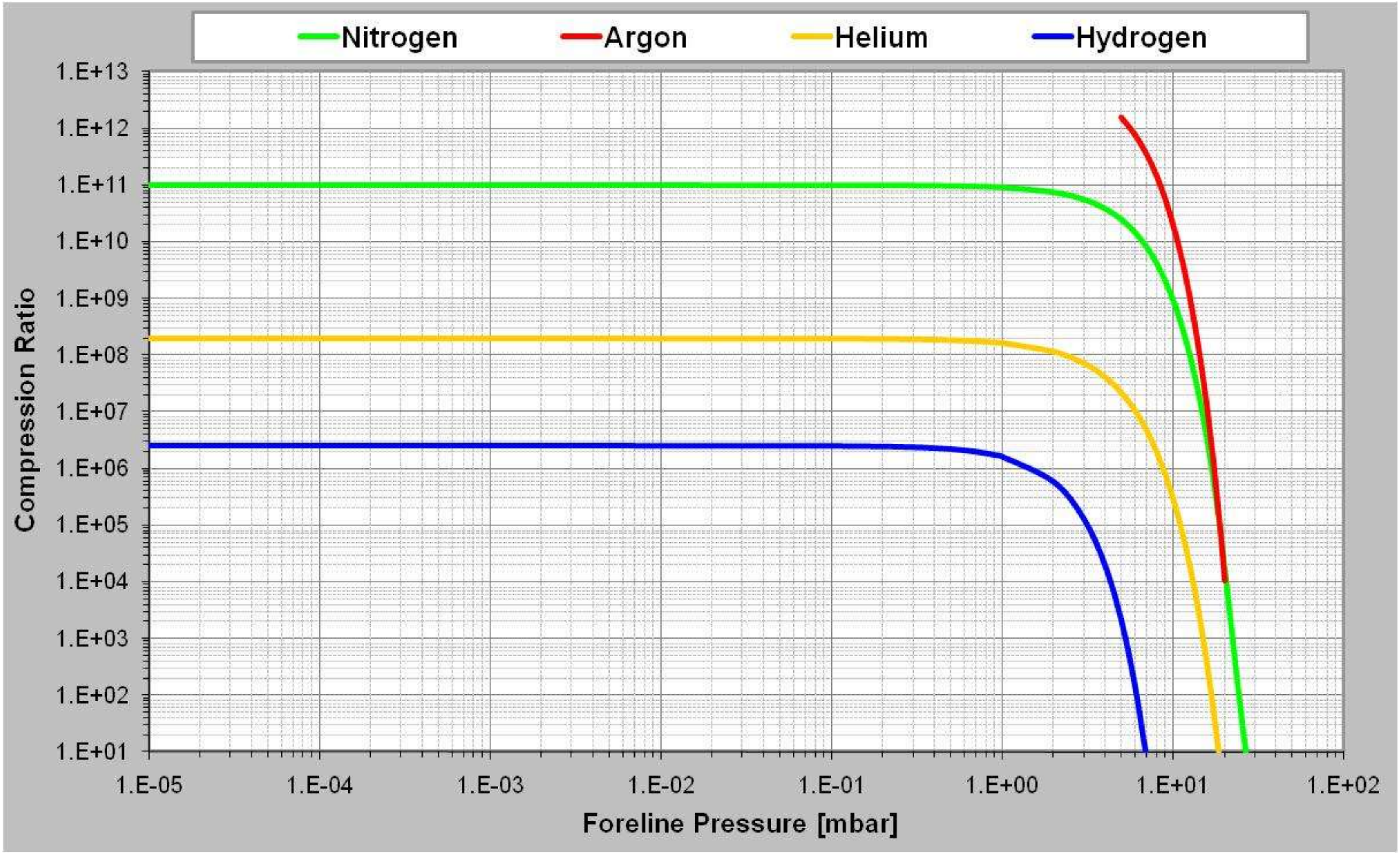
Pumping Speed



Test conditions: ISO-160 / CFF 8” flange, no inlet screen, TS-300

New Turbo-V 750 and 850 TwisTorr

Compression Ratio



Test conditions: no inlet screen, TS-300 backing pump

THANK YOU!