Design and Modeling of Fluid Power Systems

ME 597/ABE 591 Lecture 5

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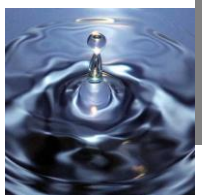

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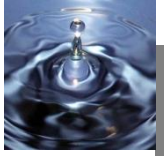
Displacement Machines



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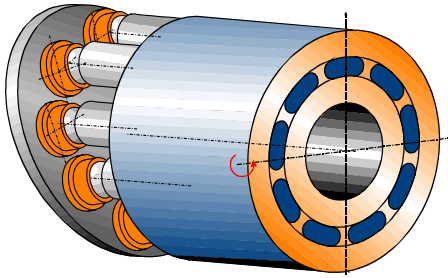
Study different design principles and learn about the following topics

Axial piston pump design solutions (swash plate and bent axis)

Radial piston pumps and motors – piston support

Gear Pumps – internal and external – axial and radial gap

Vane pumps – advantage and disadvantage of this design



Please study the appropriate chapters in
Ivantysyn, J. and Ivantysynova, M. (2001), *Hydrostatic Pumps and Motors.* Akademia Books International. New Dehli. ISBN-81-85522-16-2

Aim: - To be able to select the right design for your system application!
- Knowledge about limitations of each basic design
- To apply models on system level for each design

Displacement Machines

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- Piston Machines
  - Axial Piston Machines
    - Swash Plate Machines
    - Bent Axis machines
  - In-line Piston Machines (F)
    - with external piston support
  - Radial Piston Machines
    - with internal piston support
- Gear Machines (F)
  - External Gear
  - Internal Gear
  - Annual Gear
- Vane Machines
- Screw Machines (F)
- others

Fixed displacement machines ⟷ Variable displacement machines

Bent axis axial piston pumps

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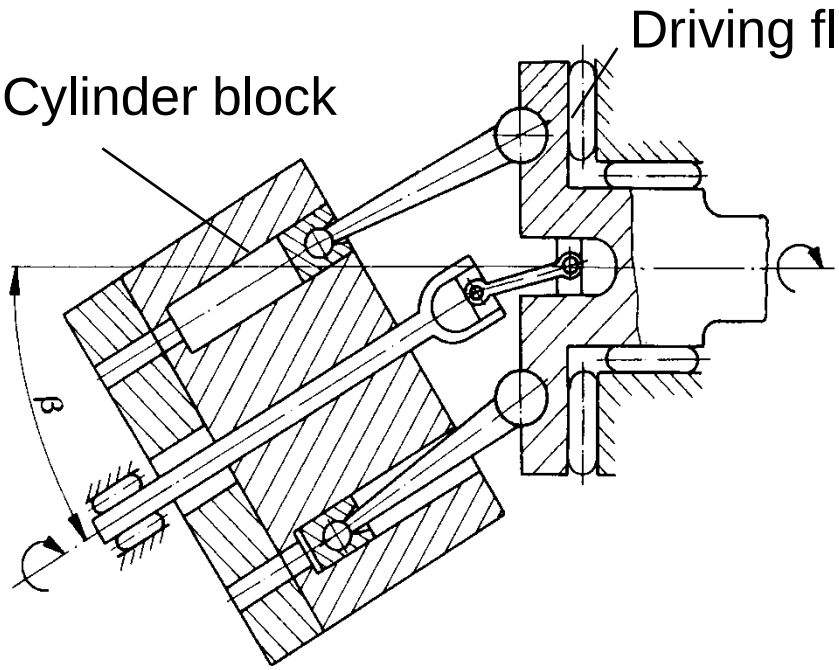
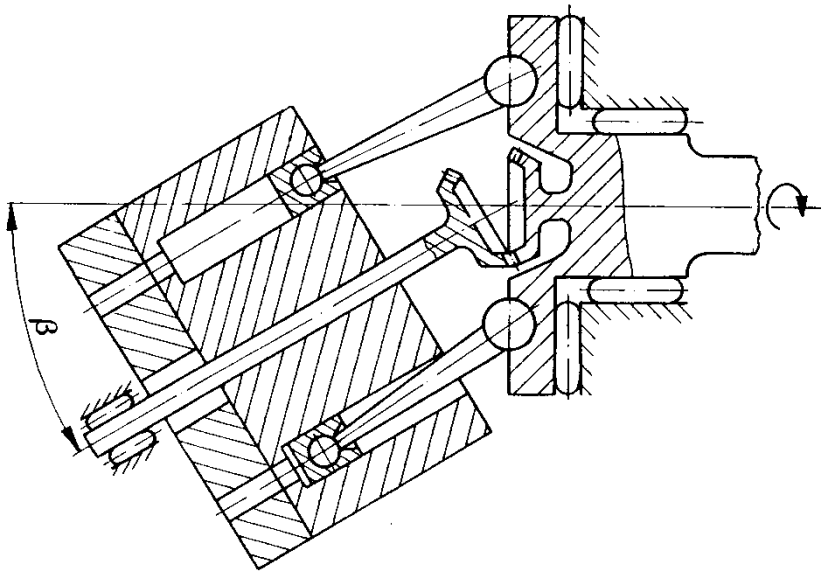
Synchronization of cylinder block



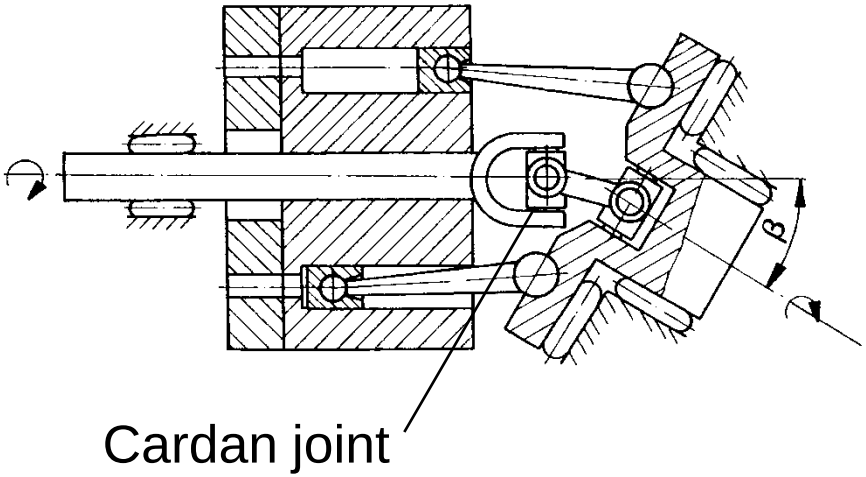
Using a universal joint

Using a bevel gear

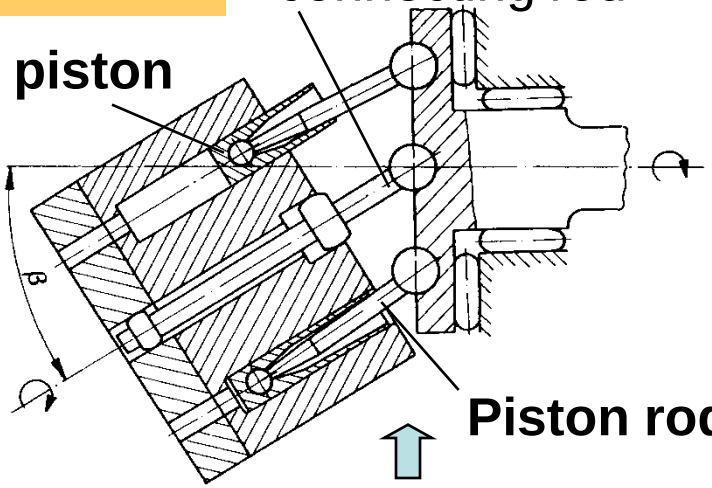


Bent axis axial piston pumps

Synchronization of cylinder block

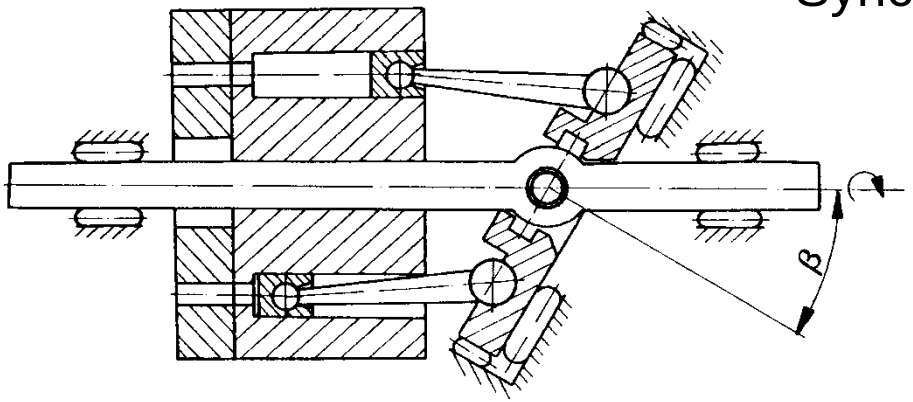


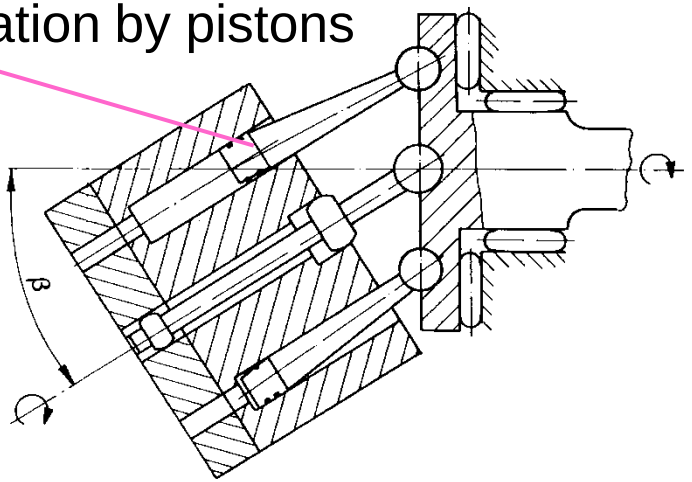
Cardan joint



Synchronization by piston rod

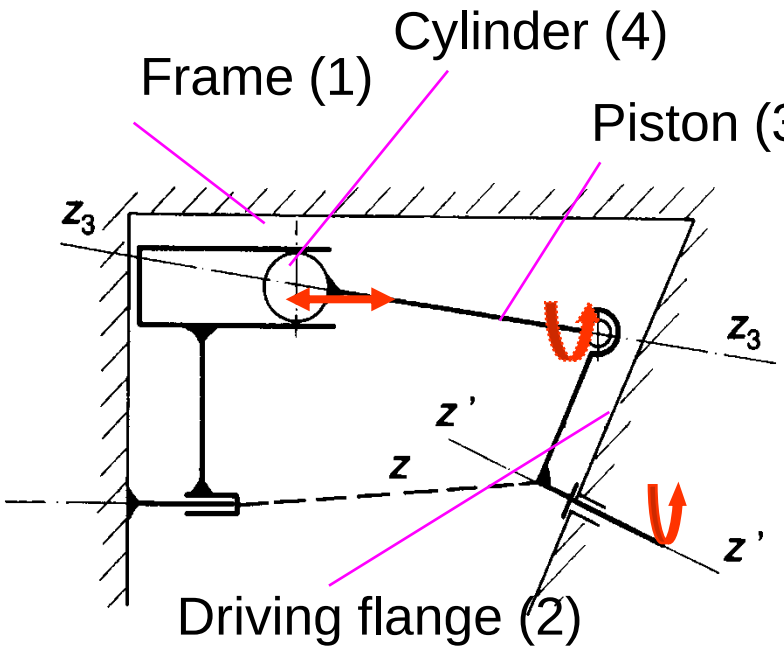
Synchronization by pistons



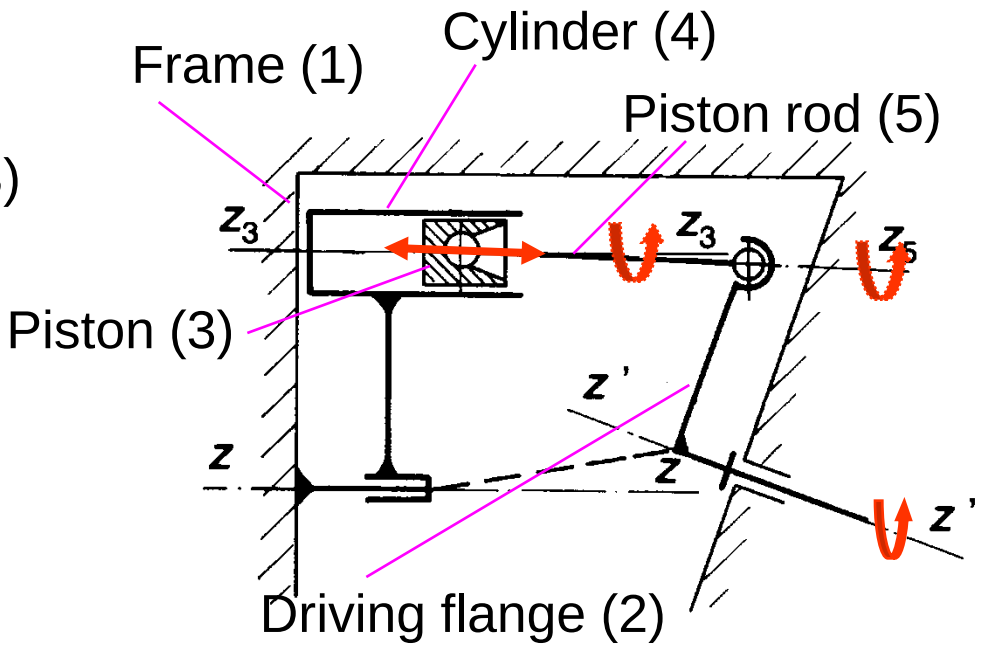


Kinematics of bent axis pumps

Four link 3D mechanism



Five link 3D mechanism



Assuming a fixed connection between link 2 and link 4, achieved by synchronization mechanism has finally two degrees of freedom

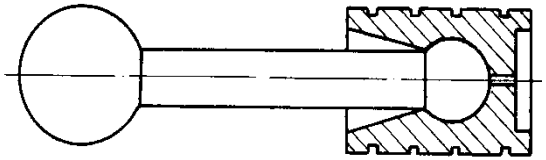
Piston can rotate about z_3-axis

the mechanism has finally three degrees of freedom

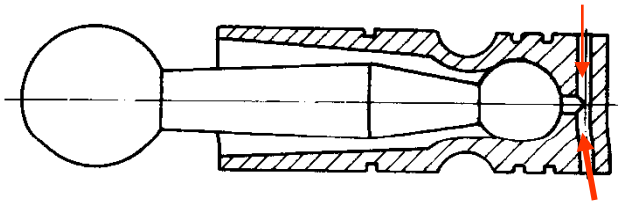
Piston can rotate about z_3-axis and piston rod can rotate about z_5-axis

Piston Design

Short piston with piston rod



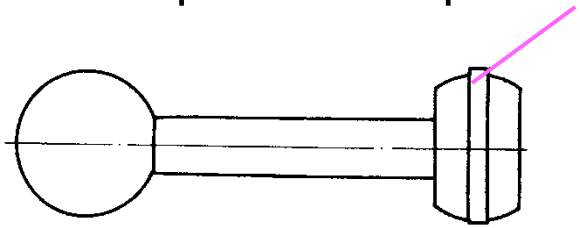
Long piston with piston rod



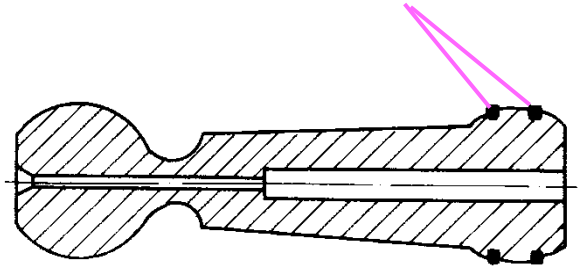
Synchronization by universal joint or bevel gear

Synchronization by pistons or piston rods

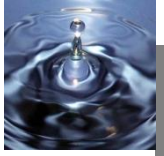
Spherical piston with piston ring



Conical piston with piston rings



Design Examples



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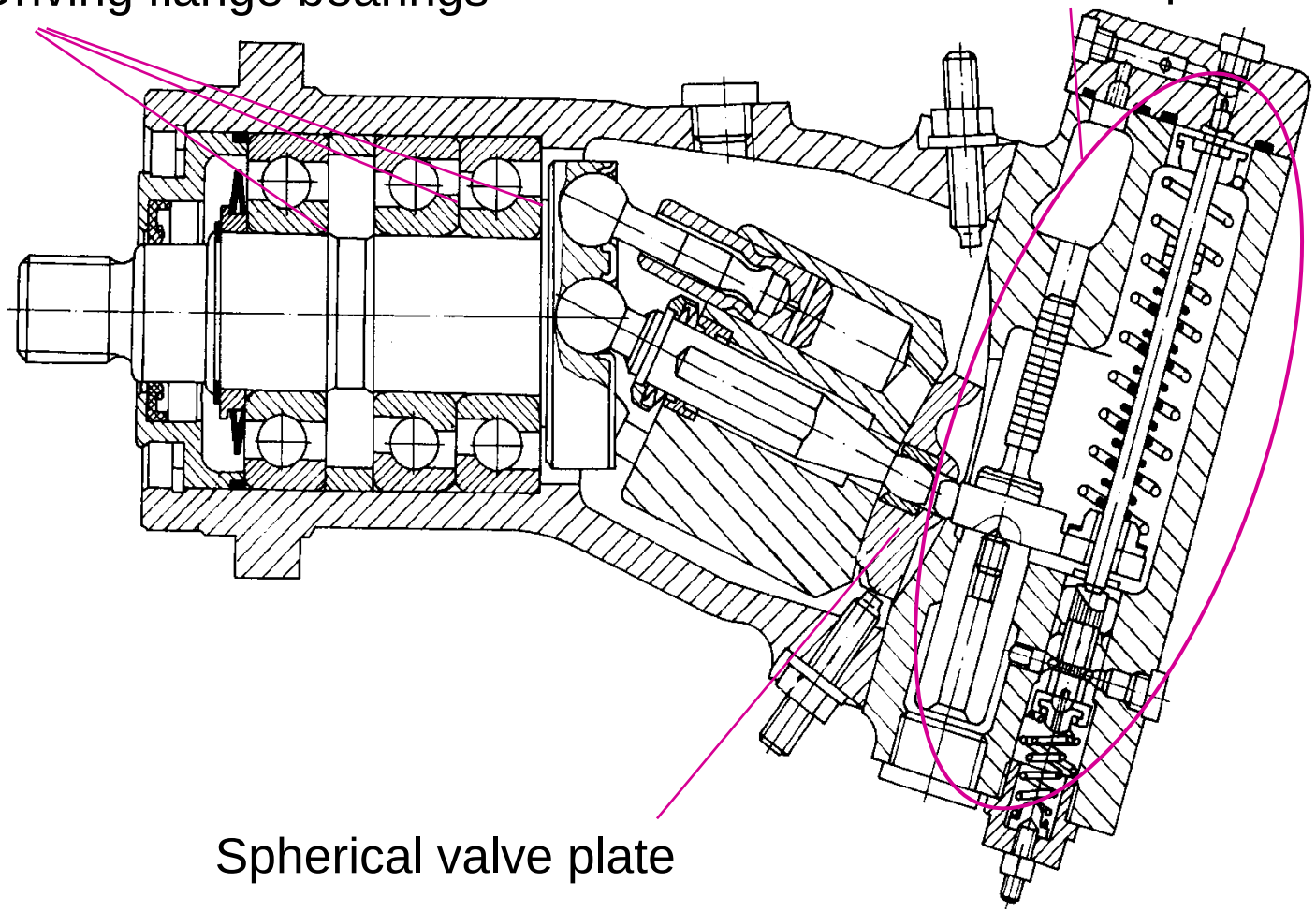
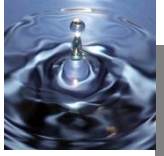
Driving flange bearings

Pump control device



Spherical valve plate

Design Examples



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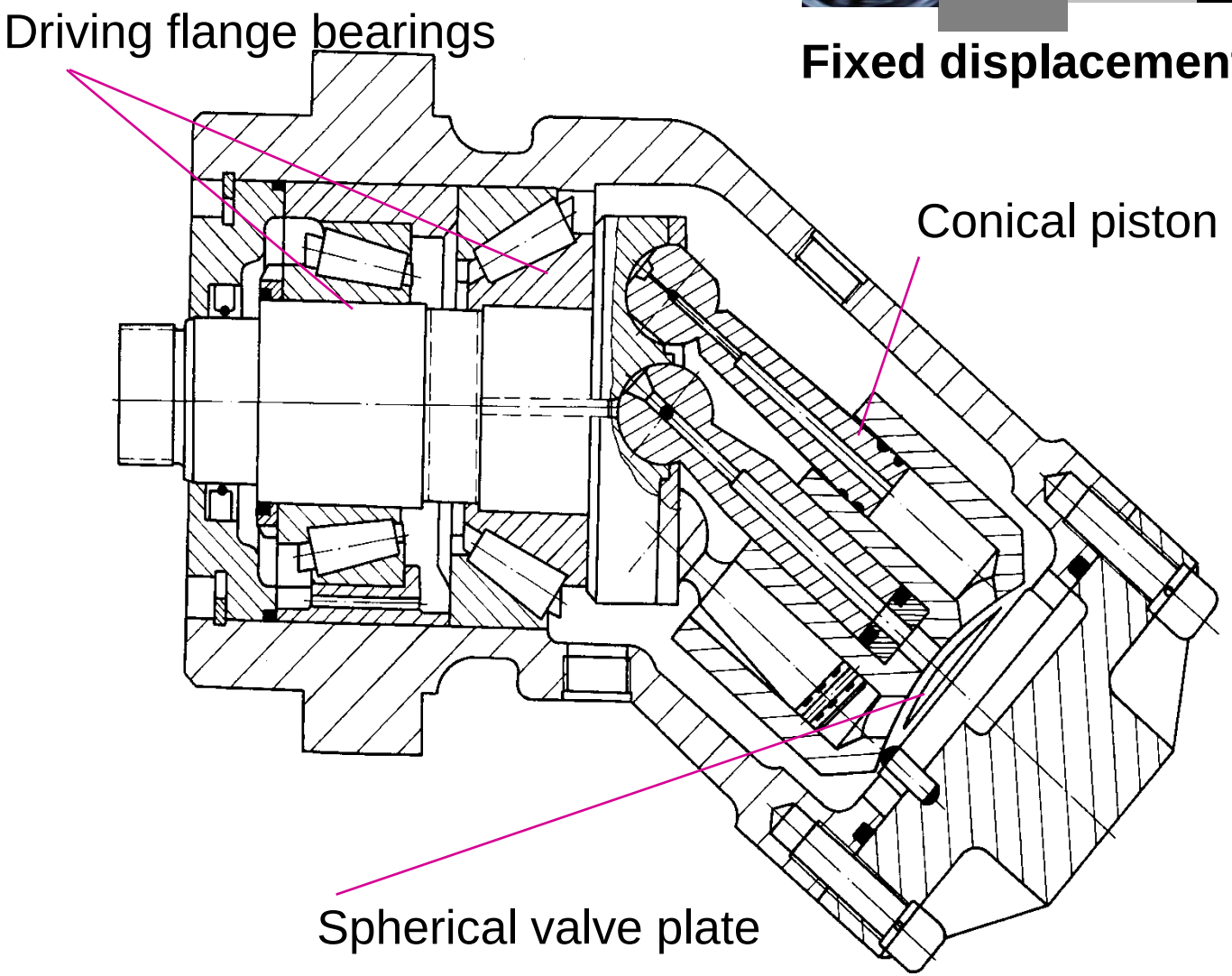
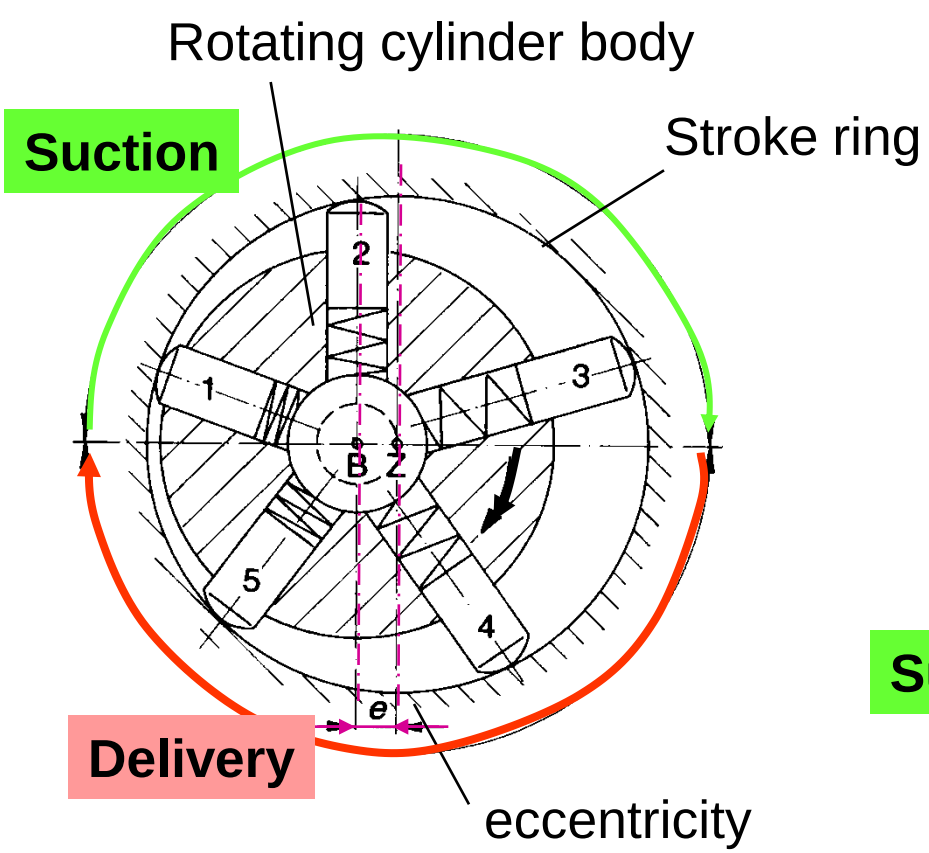
Fixed displacement pump

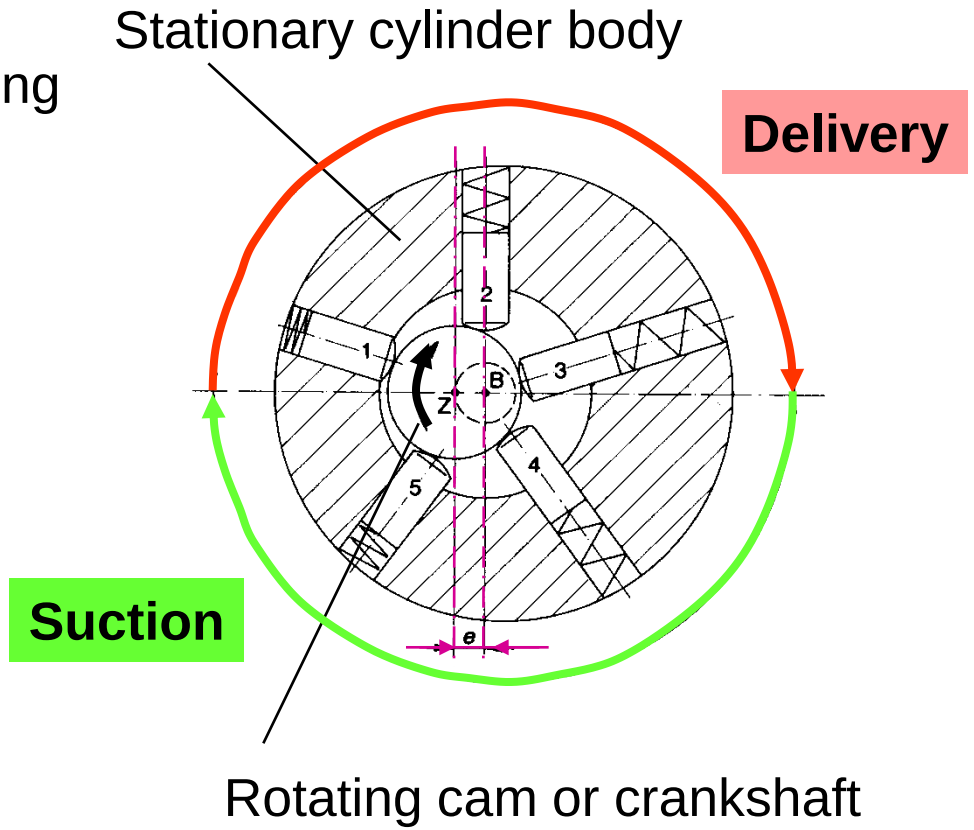


Radial Piston Pumps

with external piston support

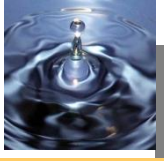


with internal piston support



Displacement volume adjustable by changing eccentricity e

Radial Piston Pumps



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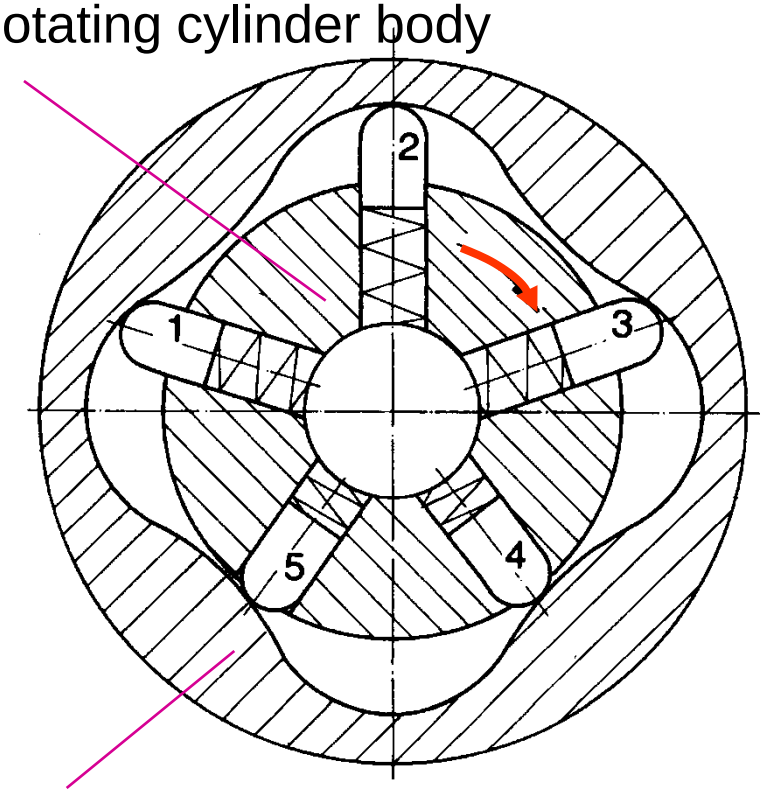
Multiple stroke radial piston pumps

with external piston support

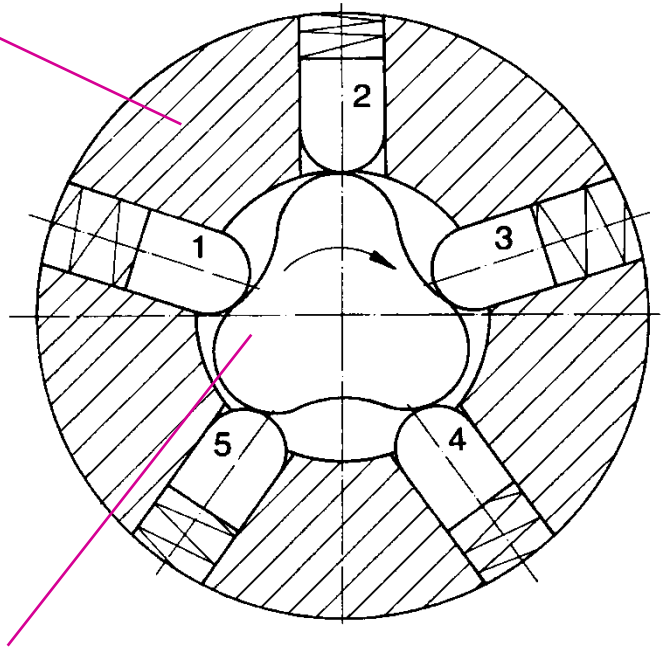
Rotating cylinder body



Stationary stroke ring

with internal piston support

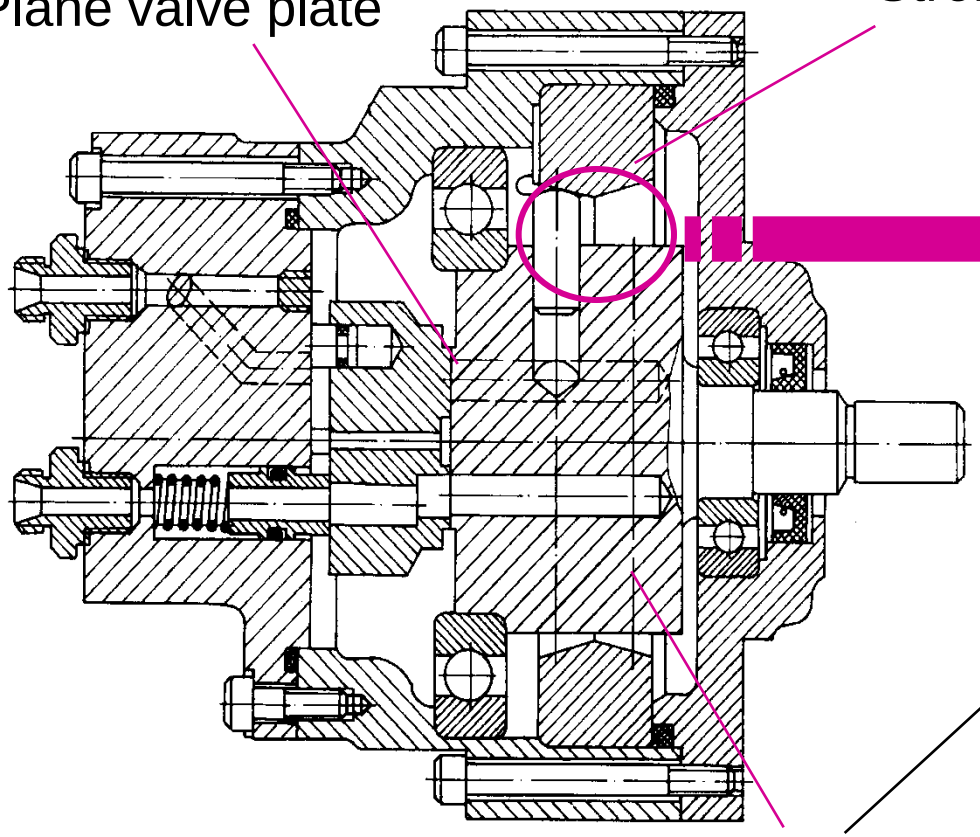
Stationary cylinder body

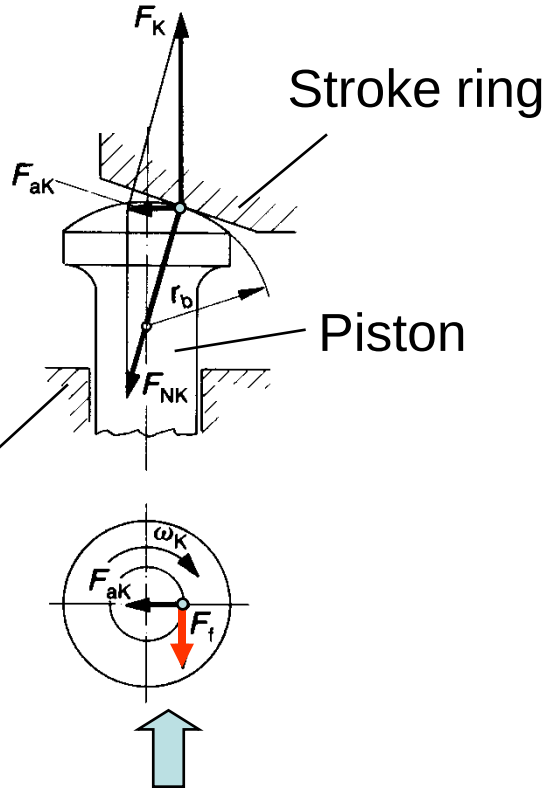


Rotating cam

Only fixed displacement pumps realizable!

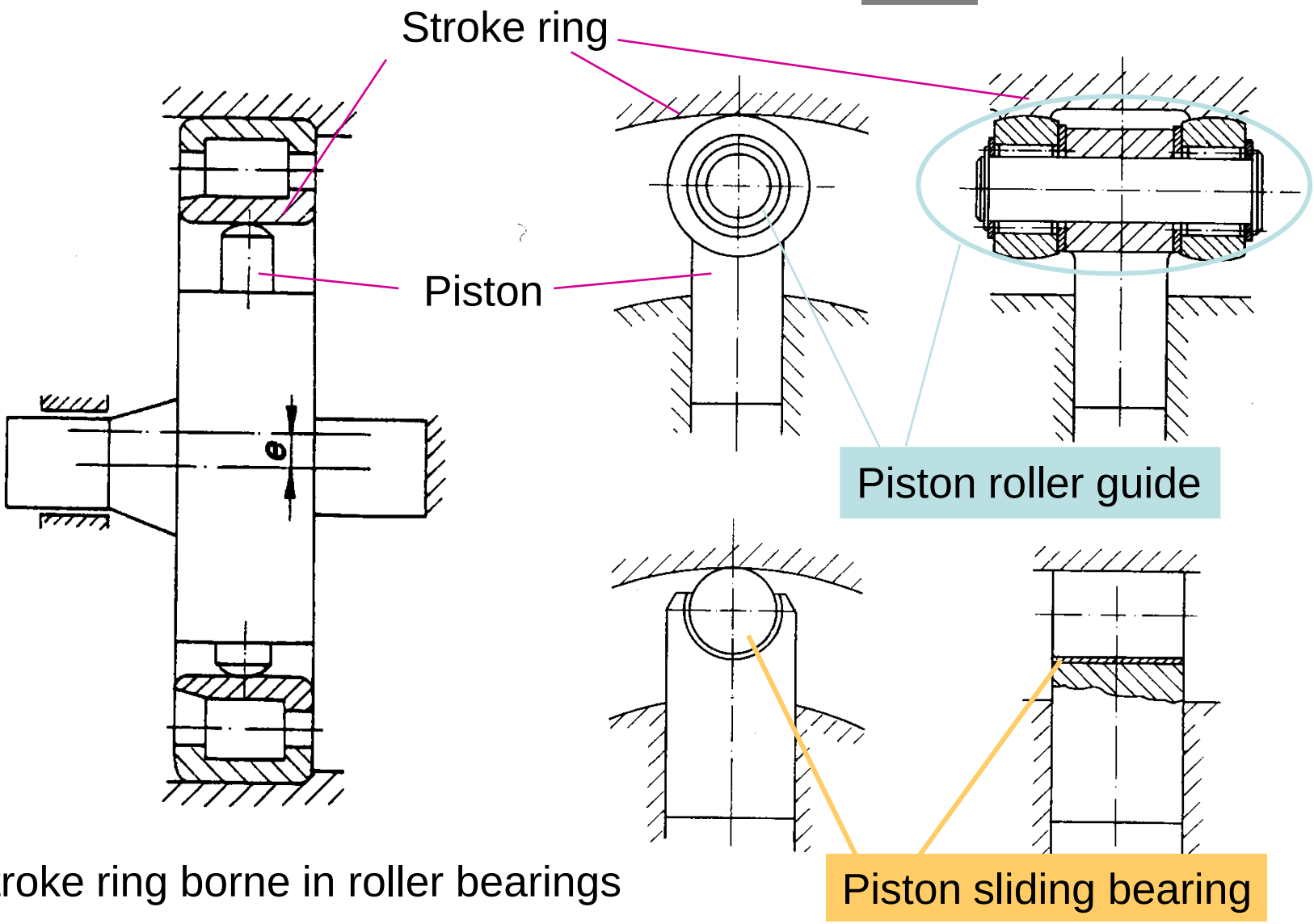
Piston support on outer stroke ring





Piston rotation enforced by friction force F_f

Piston support on outer stroke ring



Stroke ring borne in roller bearings

Piston support on outer stroke ring

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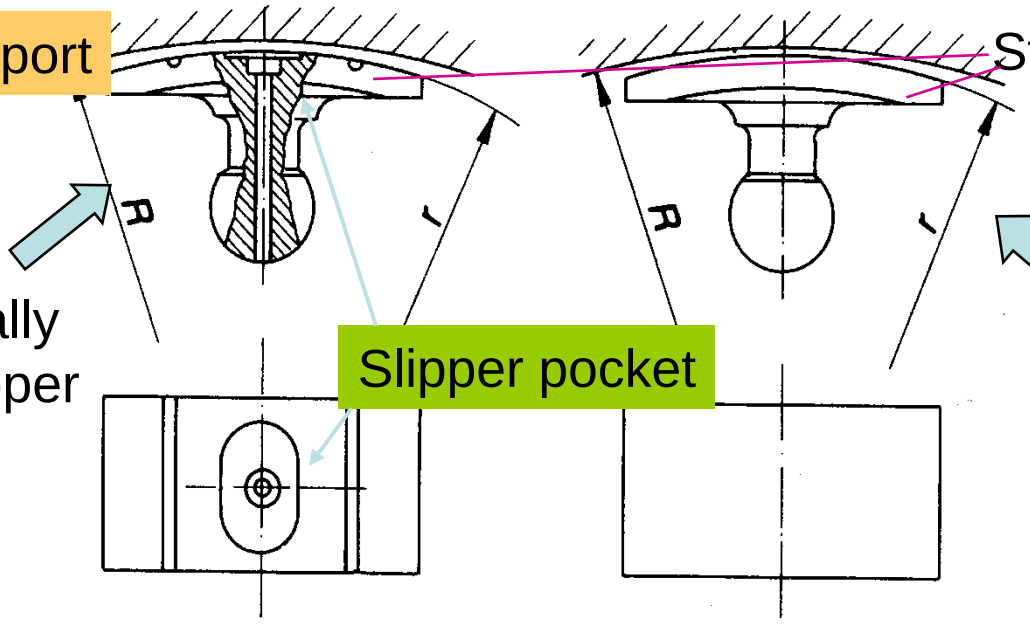
Slipper support

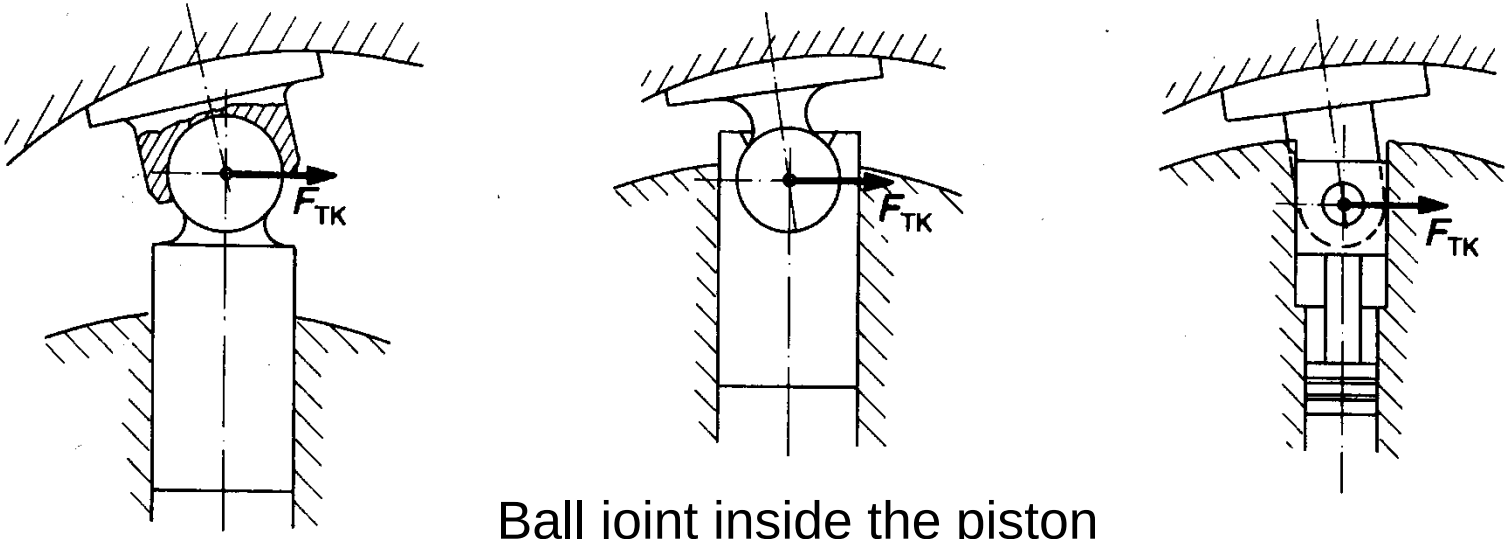
Stroke ring



Hydrostatically balanced slipper

Slipper pocket

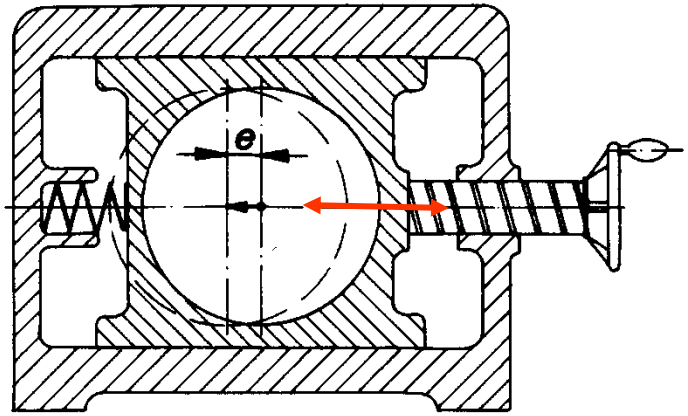
Hydrodynamically balanced slipper



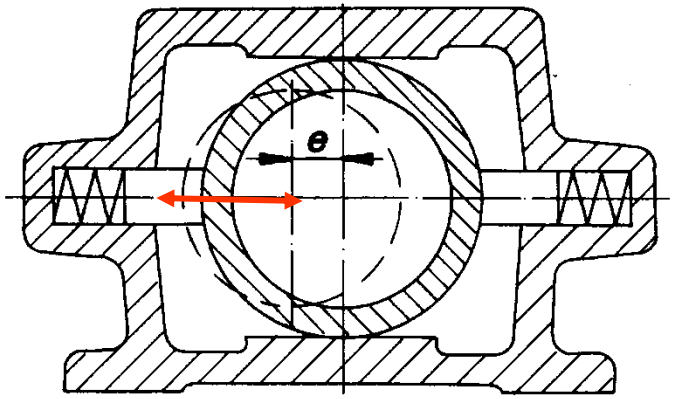
Ball joint inside the piston

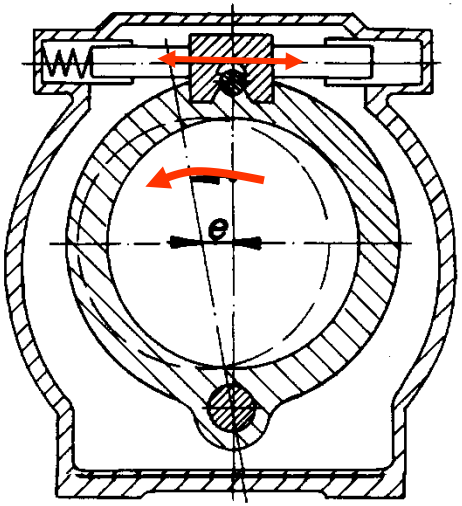
Stroke ring support

Using a sliding carriage



supported using line contact

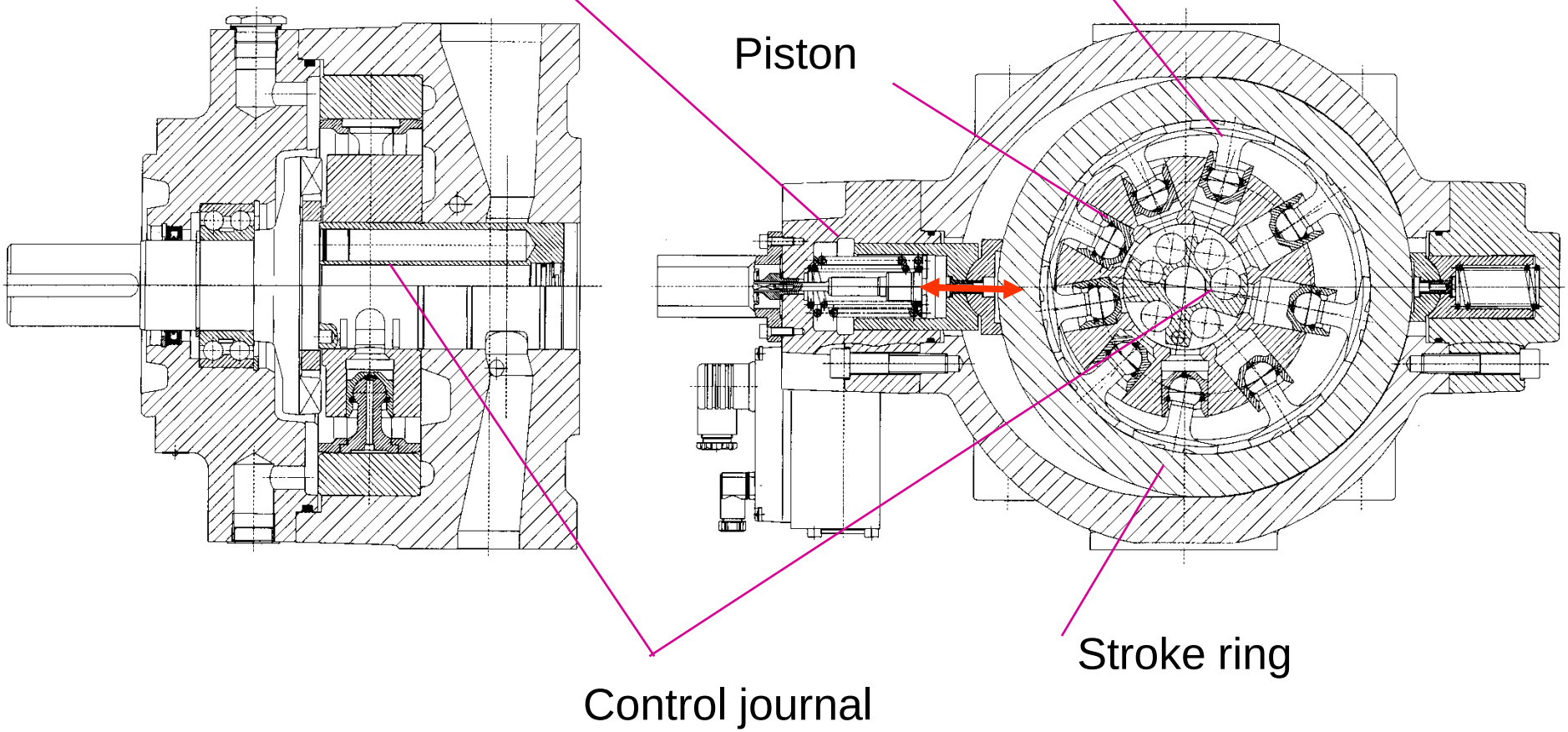




Stroke ring mounted on a pivot

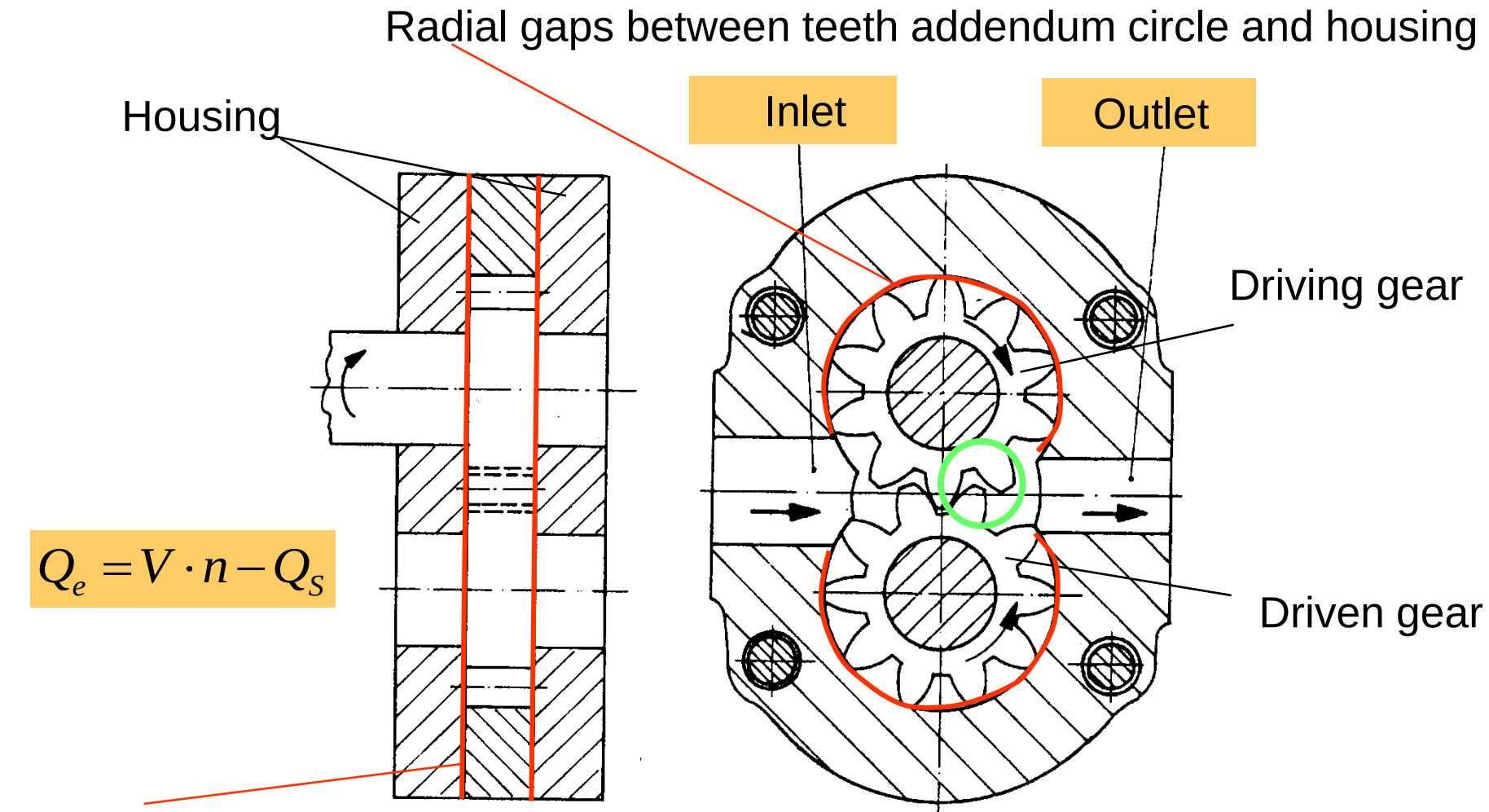
Change of eccentricity by pivoting the stroke ring about pivot axis

Design Example

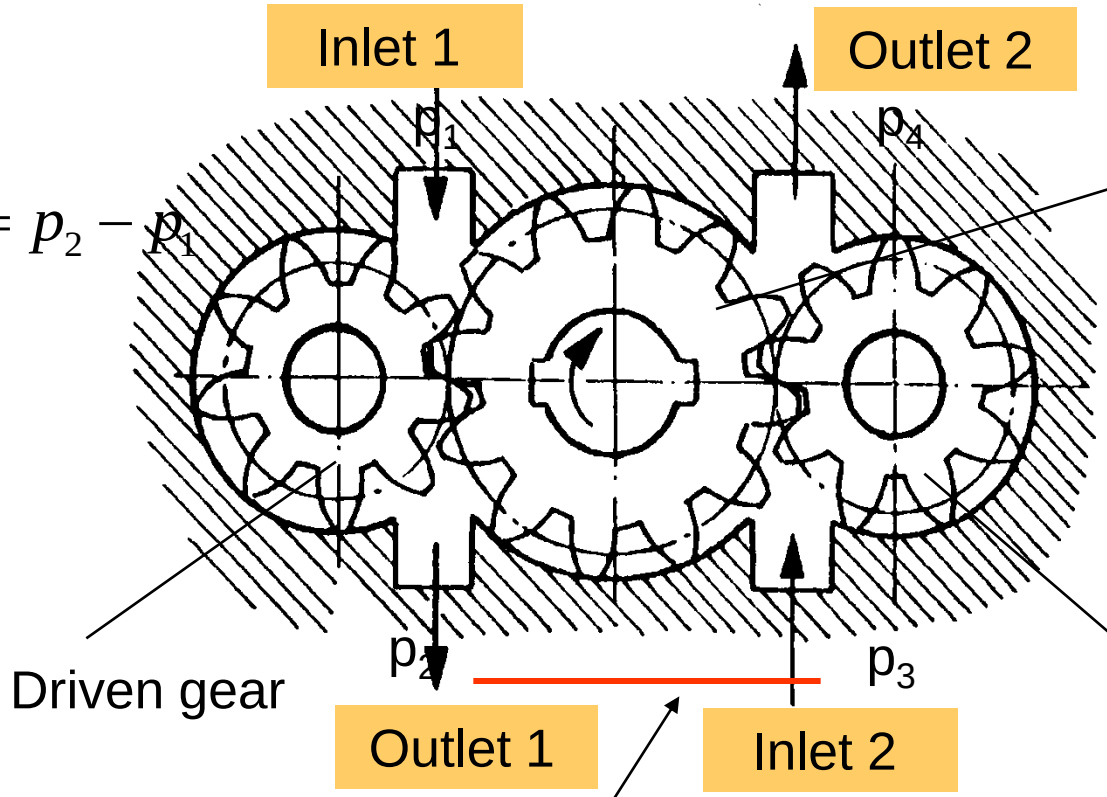


External gear pump

Basic principle



Two stage gear pump

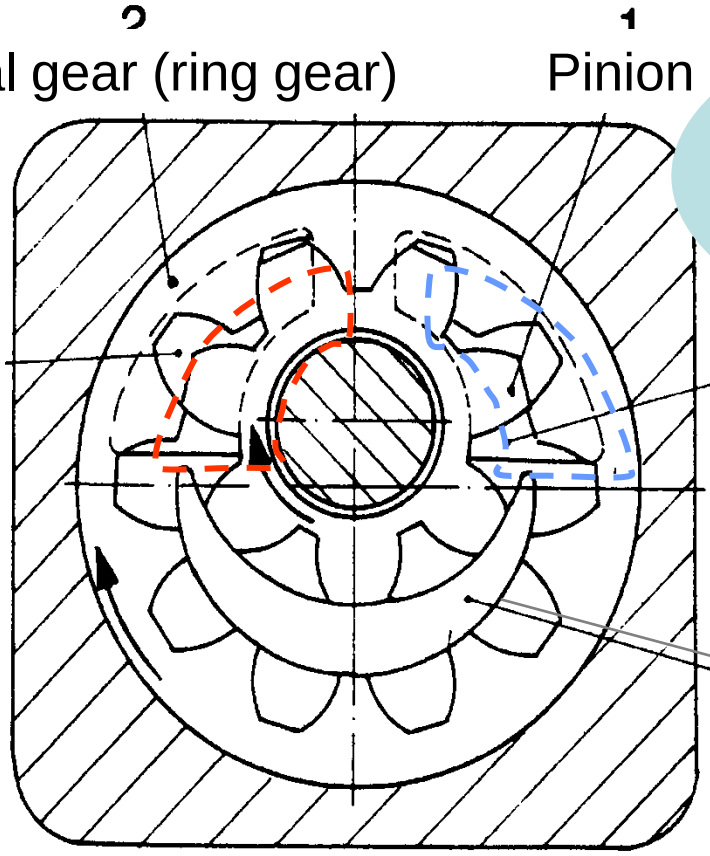


Outlet 1 and inlet 2 can be connected ⇒ $p_2 = p_3$

or the pump can have two separate outlets ⇒ $p_1 = p_3$

$\Delta p_1 \approx \Delta p_2$ ⇒ the driving gear is pressure balanced!

Internal gear pump

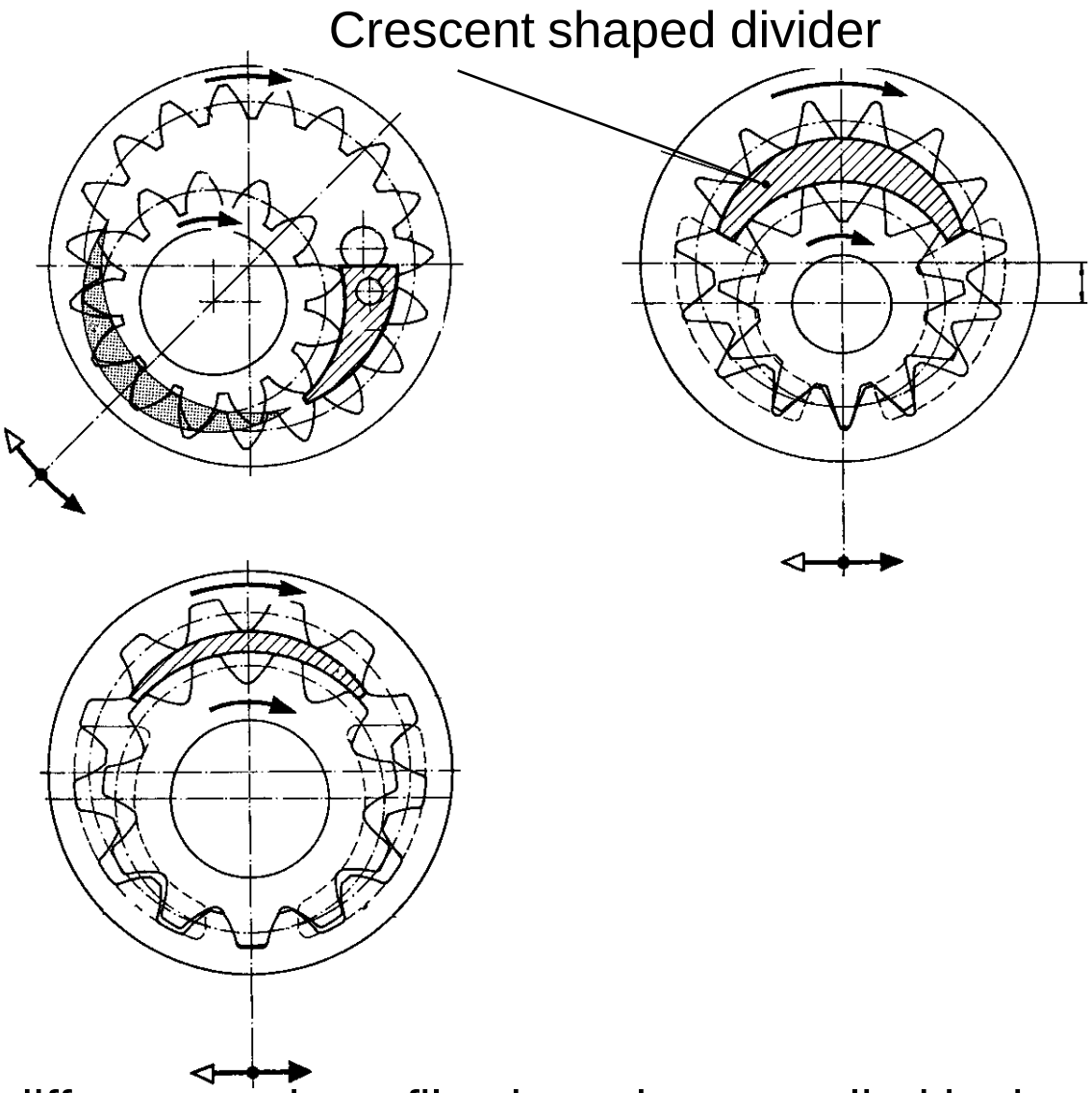


Advantages:
Better suction ability
Higher efficiency
More compact design
Less noise emission

Using teeth of standard involute design requires a combination where the pinion has two or more fewer teeth than the ring gear! Pinion and ring gear are then separated by a crescent shaped divider.

⇨ Longer duration of teeth meshing leads to better sealing function

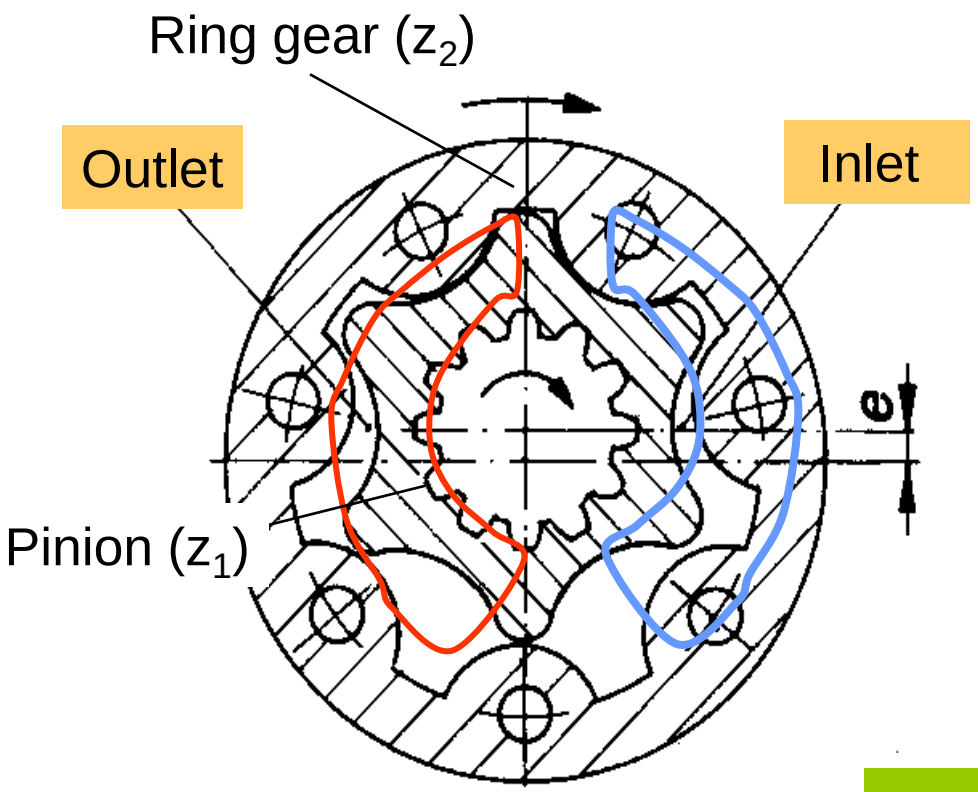
Internal gear pump



Many different tooth profiles have been applied in the recent past.

Annular gear pumps

Applying specially generated tooth curves it can be achieved, that the inner rotor (the pinion) has only one tooth less than the ring gear, thus eliminating the crescent-shaped divider.



Gerotor pump

$$z_2 = z_1 + 1$$

Each tooth of the pinion maintains continuous sliding contact with a tooth of the ring gear, providing fluid tight engagement.

Relative sliding velocity between pinion and ring gear is very small

quiet operation and long service life

$$n_2 = n_1 \cdot \frac{z_1}{z_2} = n_1 \cdot \left(1 - \frac{1}{z_2}\right) = n_1 \cdot \left(1 + \frac{1}{z_1}\right)^{-1}$$

Annular gear pump – Orbit principle

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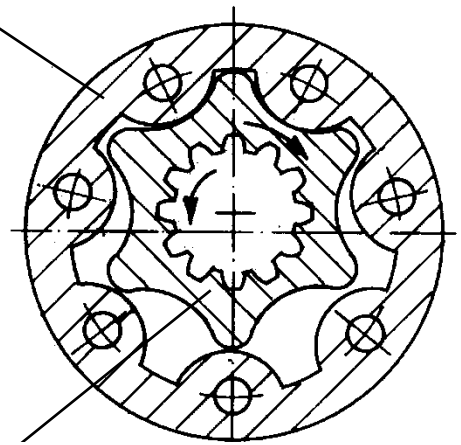
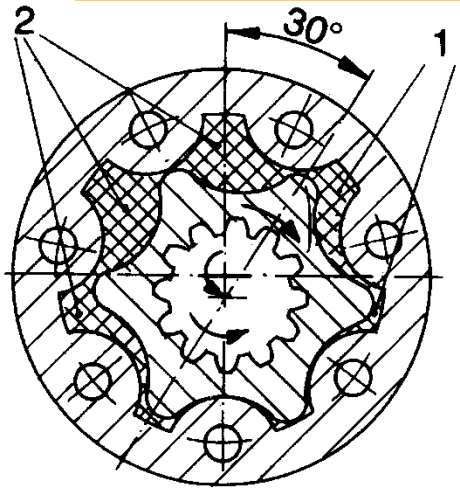
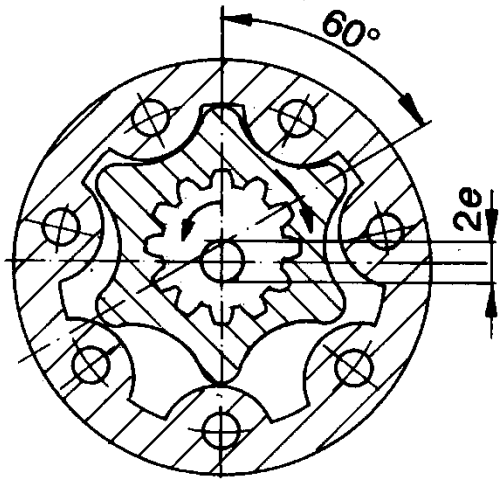
Ring gear (z_2) fixed

Rotating pinion (z_1)

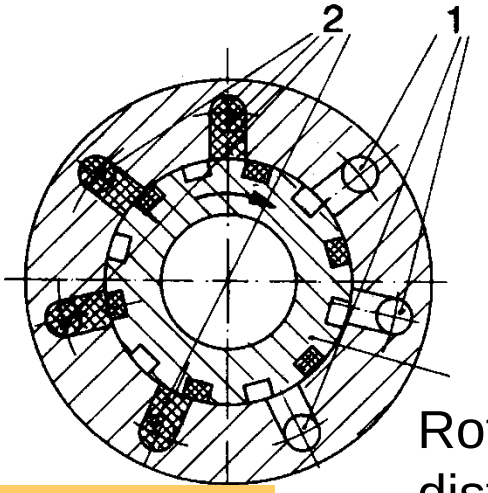


2 Pressure port





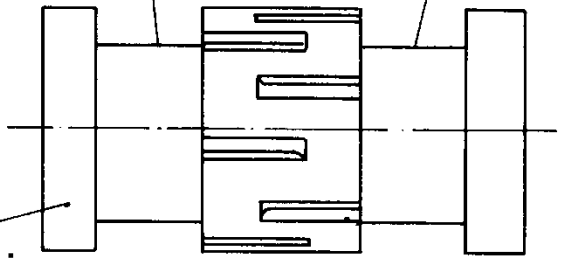
$z_2 = z_1 + 1$



1 Suction port

Outlet

Inlet



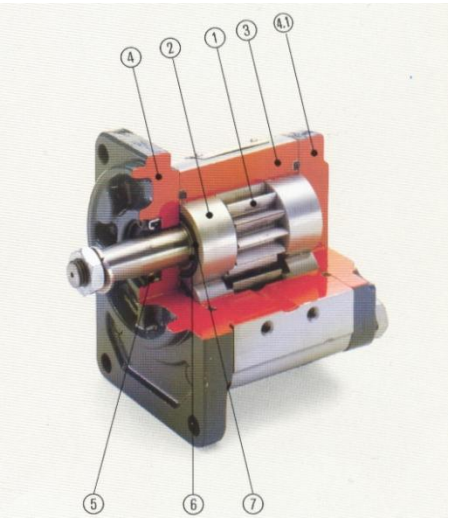
Rotating distributor

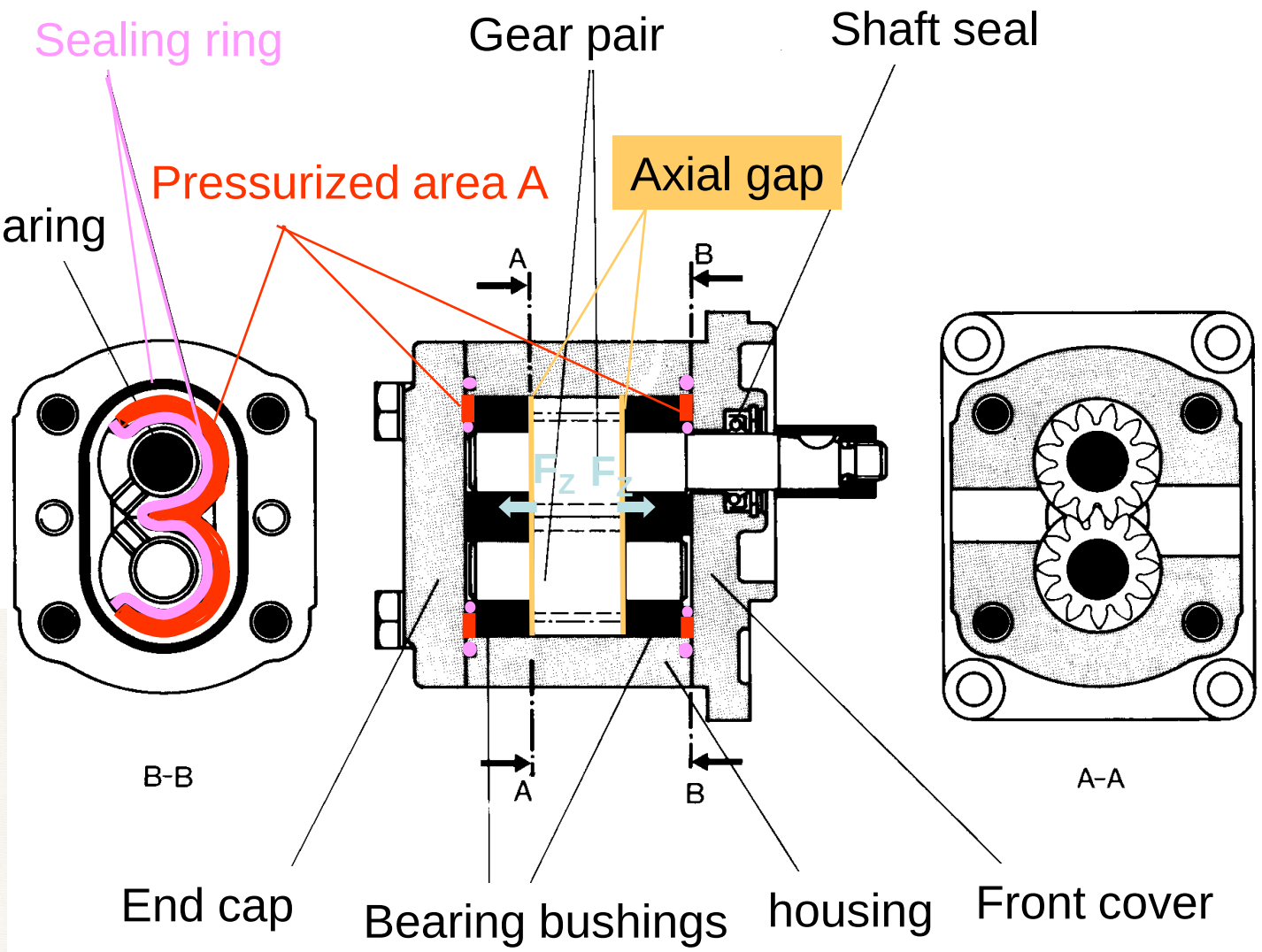
Displacement volume is given by z_1 times z_2 tooth spaces

Multiple delivery of each tooth space

Pressure compensated axial gaps

$$A = (1.1 \div 1.3) \cdot \frac{F_z}{p_2}$$

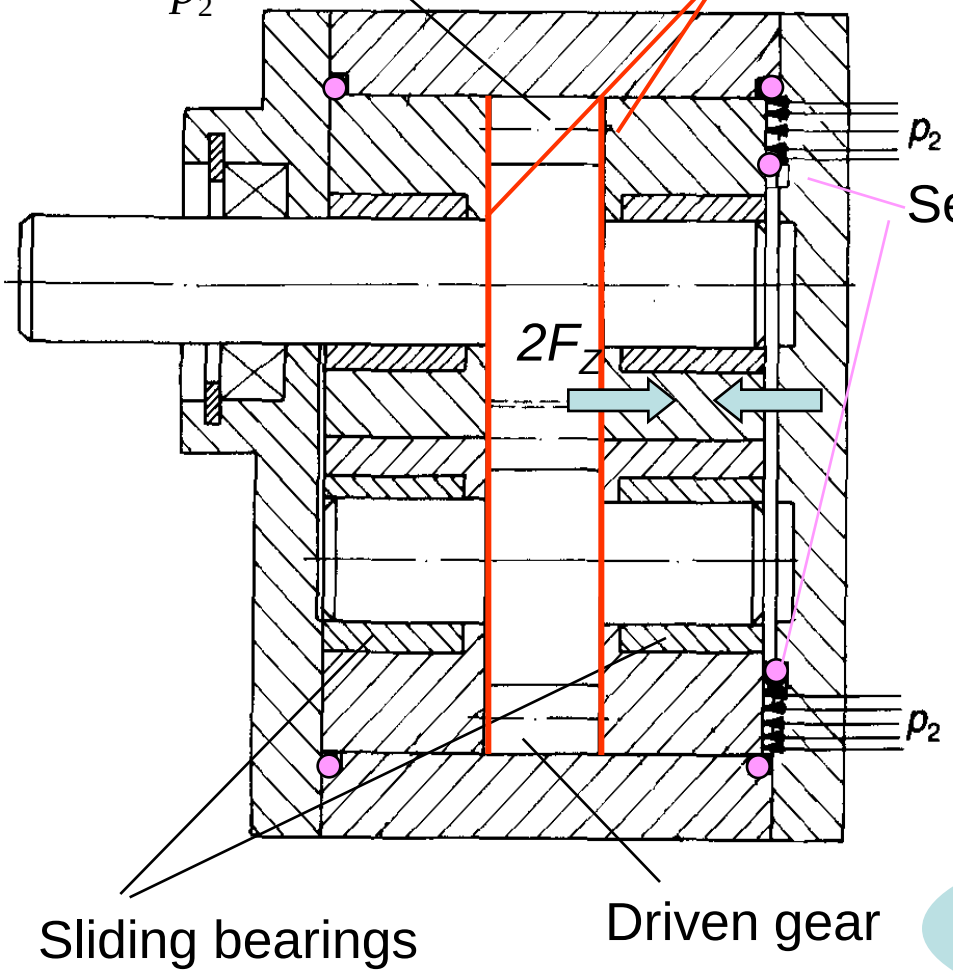


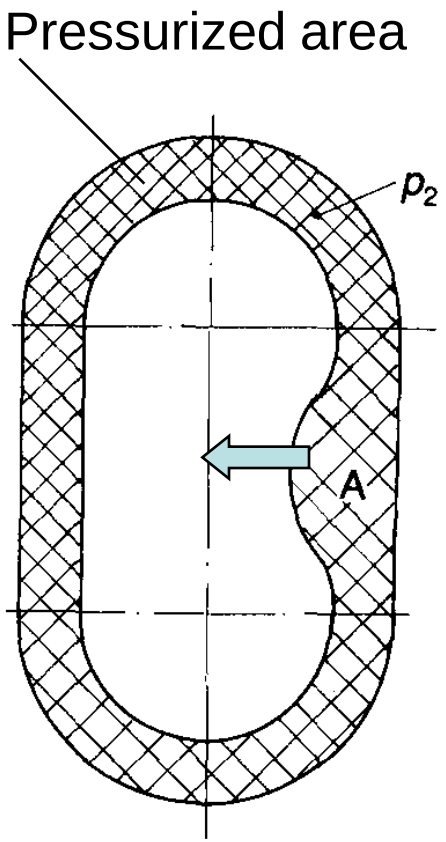


Only one direction of shaft rotation possible!

Pressure compensated axial gaps

$$A = (1.1 \div 1.3) \cdot \frac{2 \cdot F_z}{p_2}$$

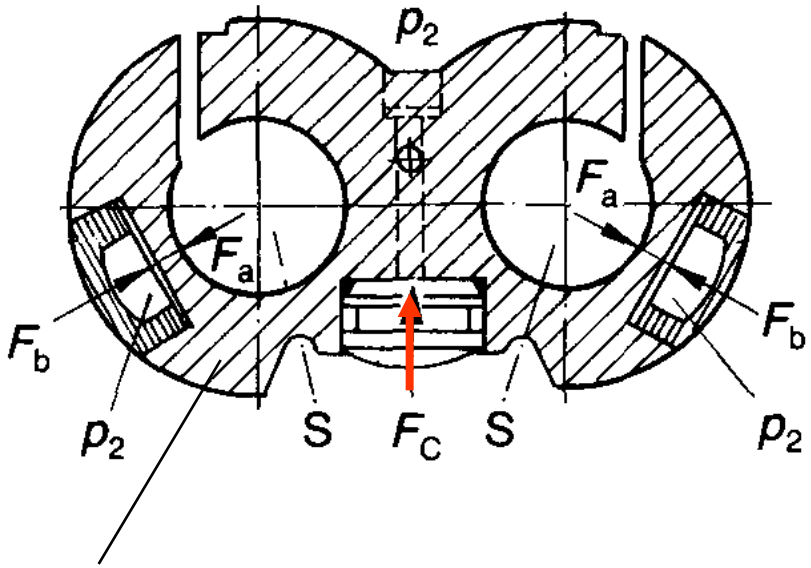




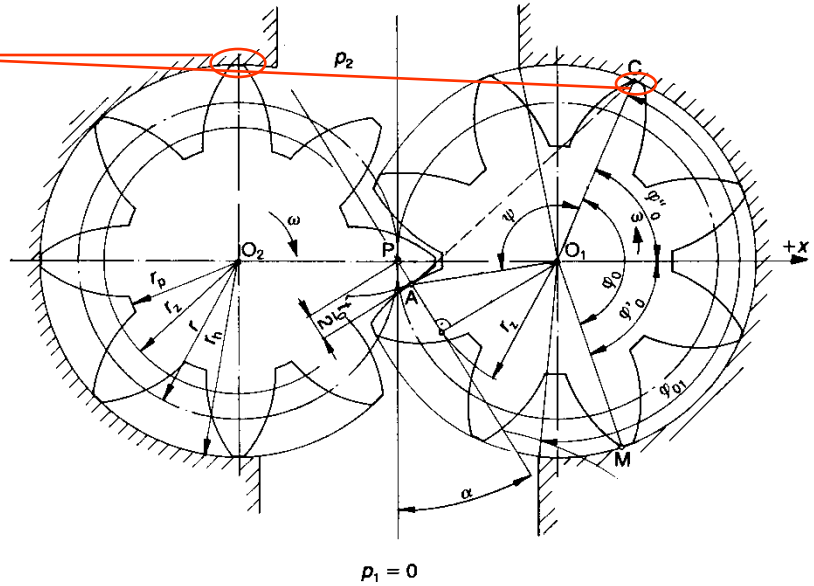
Improved volumetric efficiency

Pressure compensated radial gaps

Radial gap compensation

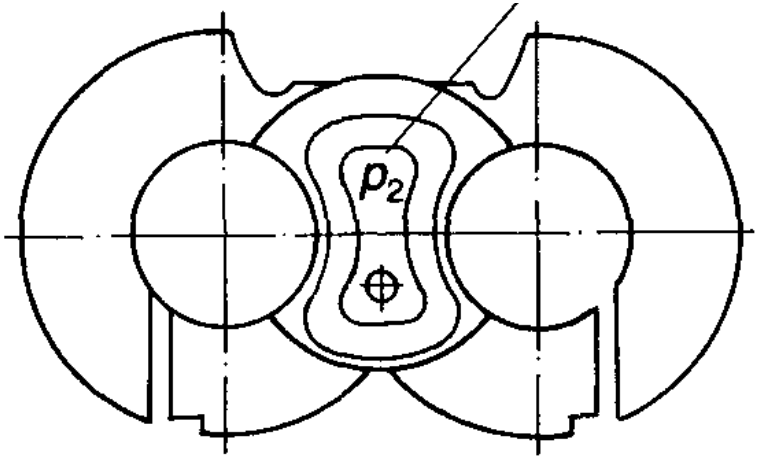


Bearing bushing



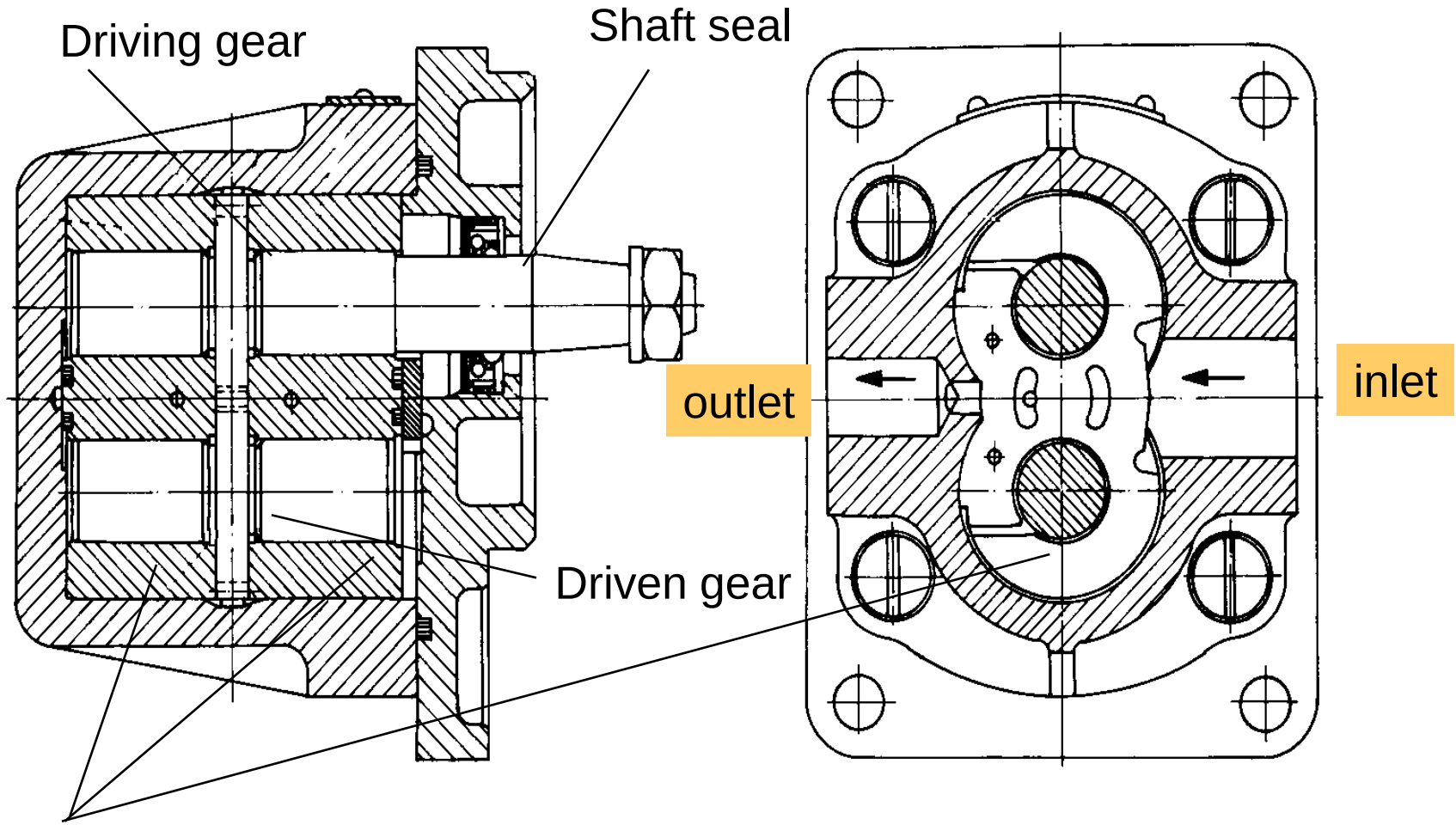
Axial gap compensation

Pressurized area



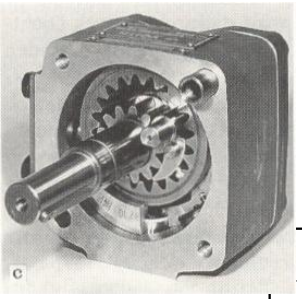
Small pressure zone achievable

Gear pump – design example

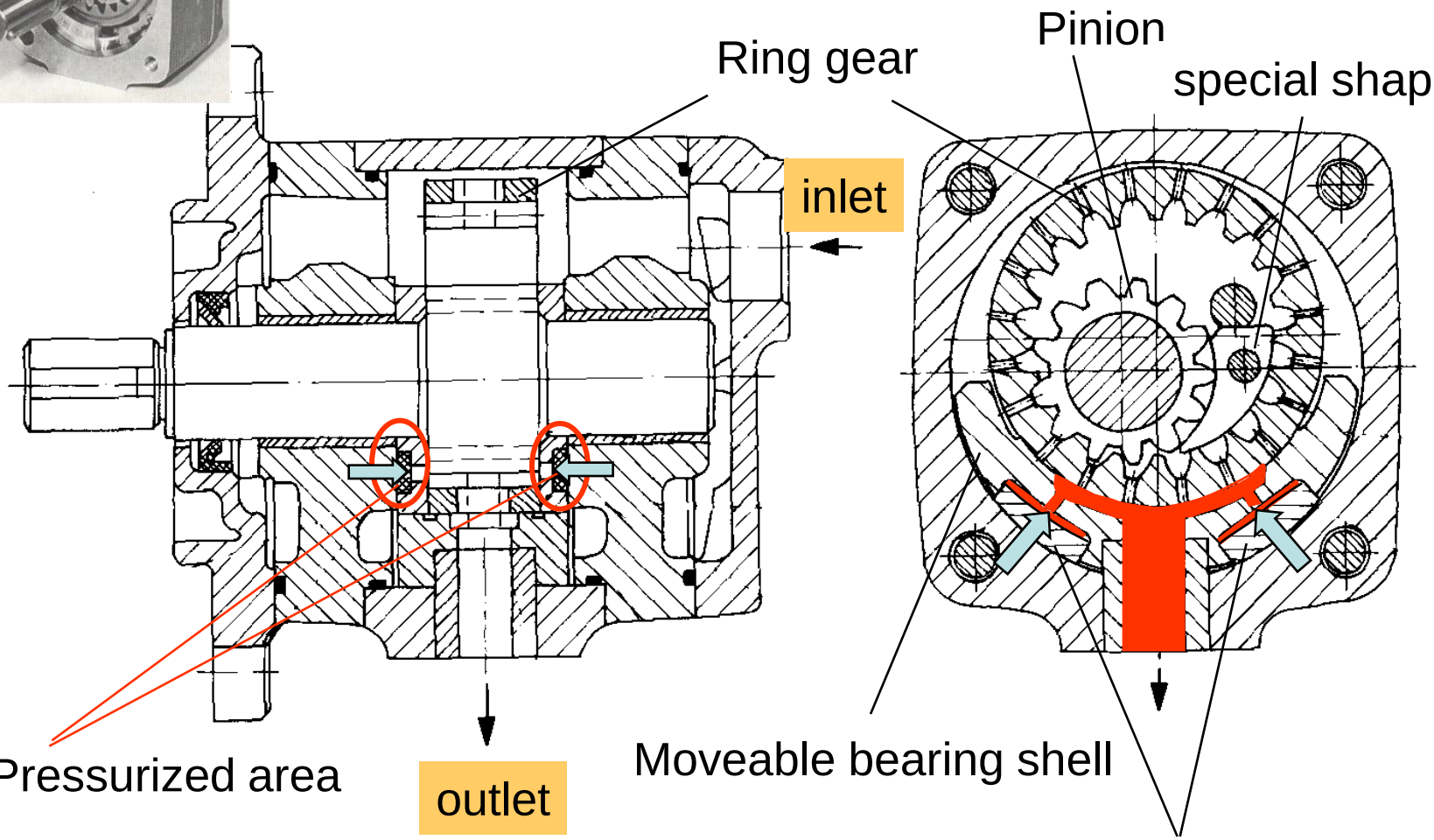


Bearing bushing performing a radial and axial gap compensation

Internal gear pump- design example

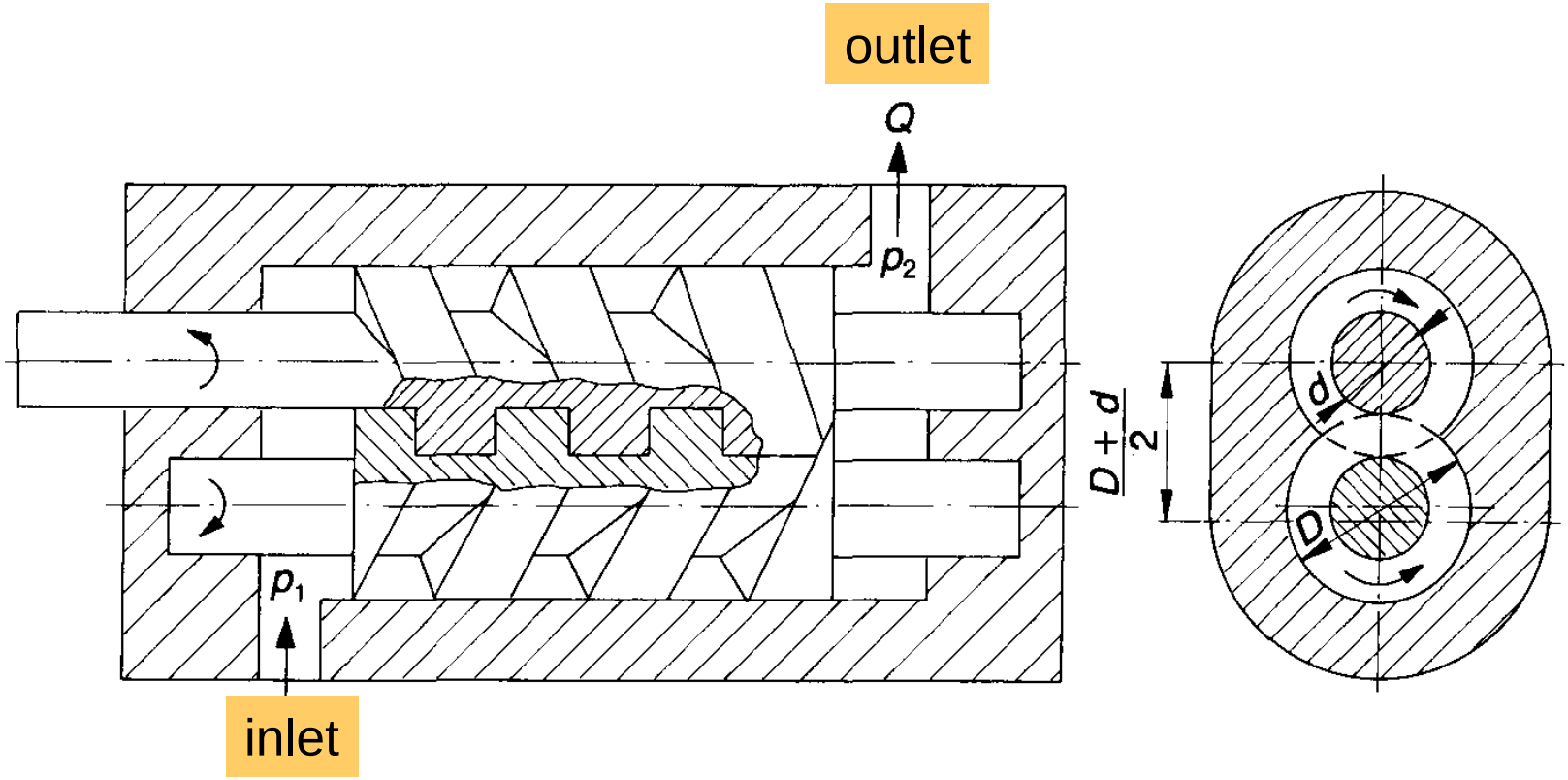


Internal gear pump with axial and radial gap compensation

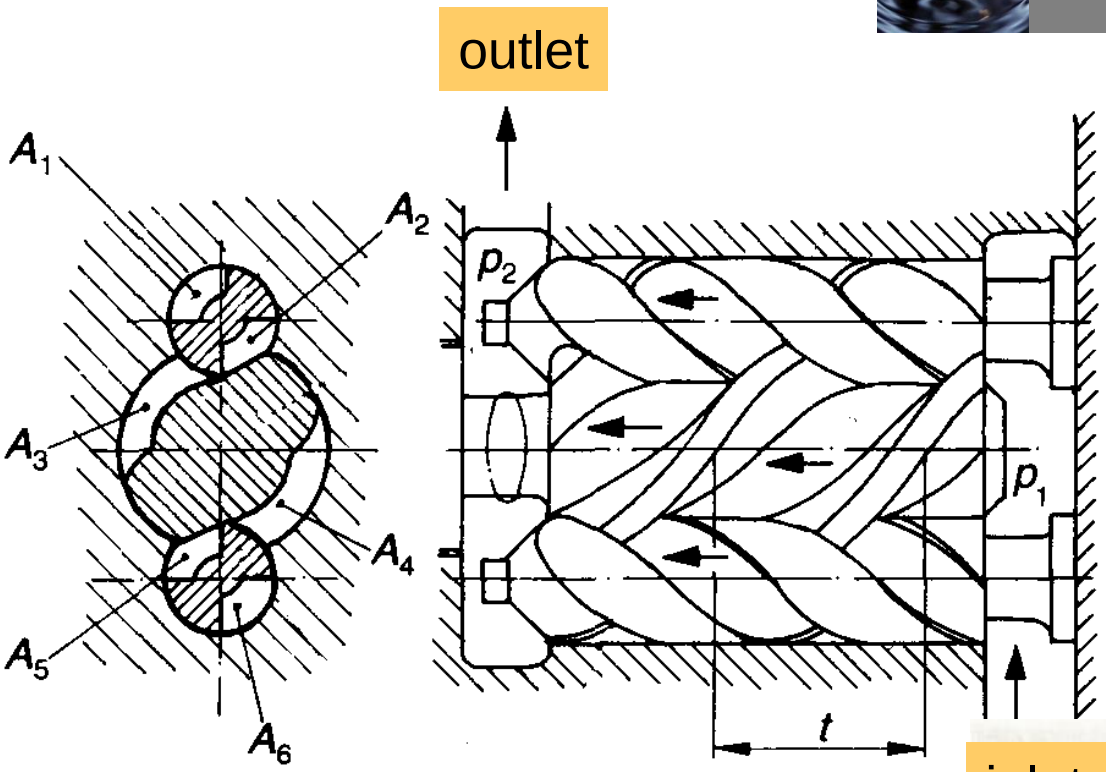


Screw Pumps

With two meshing screws

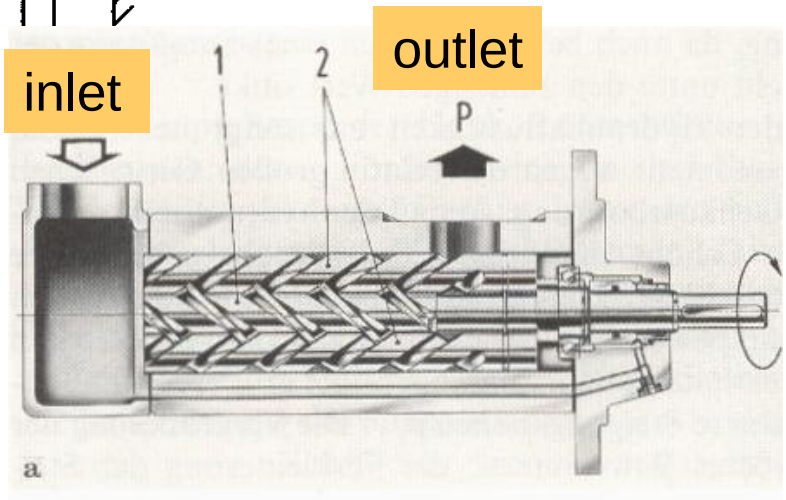


Screw Pumps



t…thread pitch

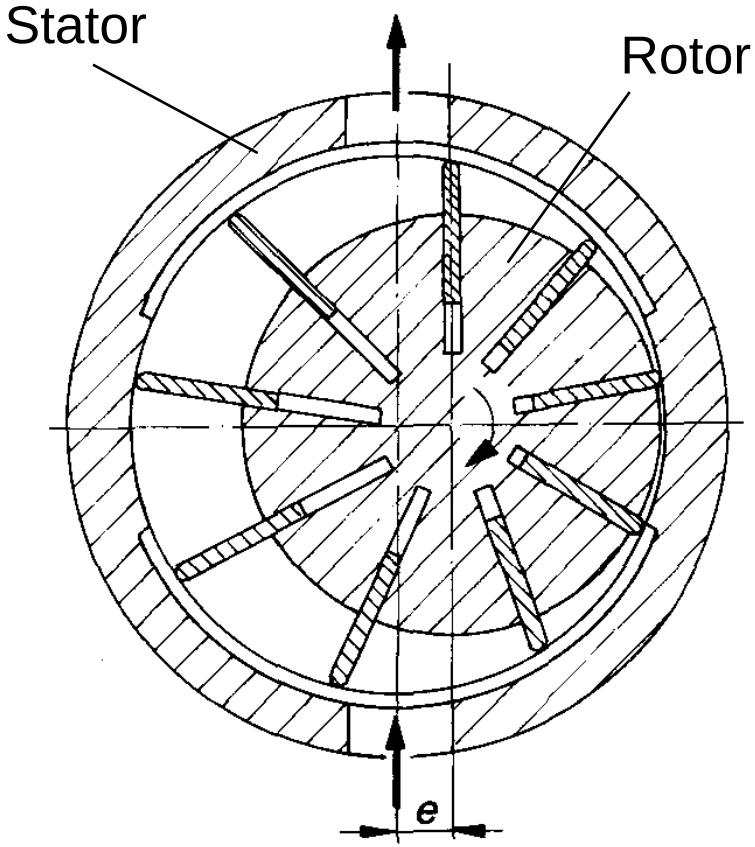
With three meshing screws



Vane Pumps

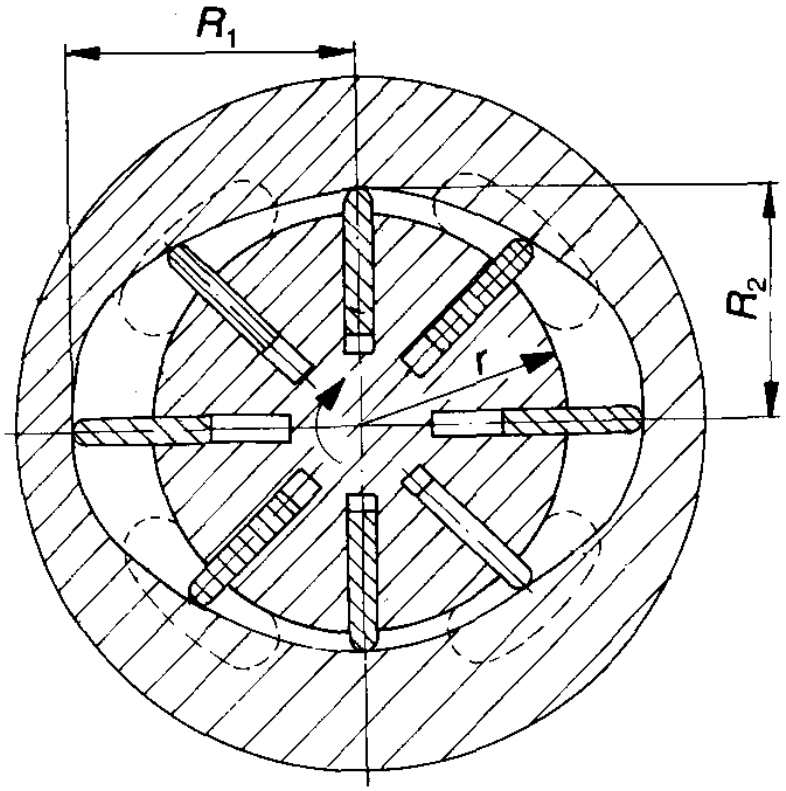
Classification of vane pumps

Unbalanced vane pump



Fixed and variable pump design

Balanced vane pump

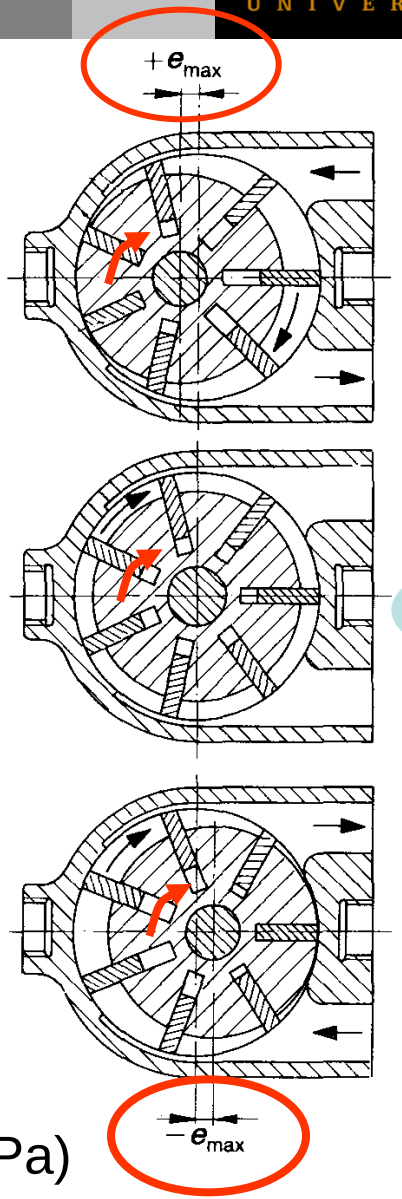


Only fixed displacement pump

Vane pumps- basic working principle

Single stroke vane pump – variable displacement volume

Overcentre pump – the direction of flow can be reversed by change of eccentricity, i.e. without changing the direction of rotation of the drive shaft



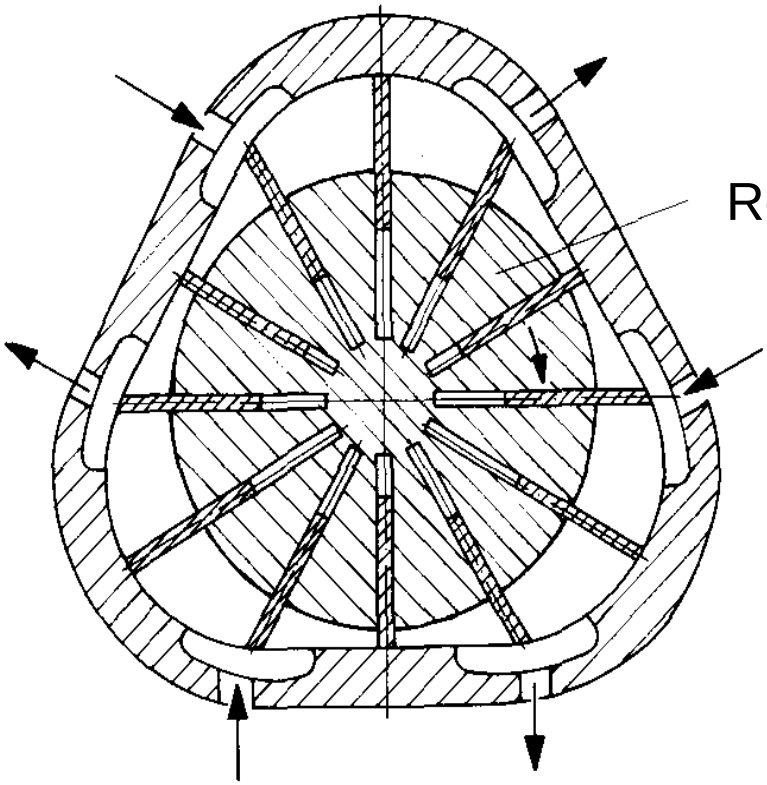
Relatively high friction between axial moveable vanes and rotor
&
between vanes and stator

Large radial forces exerted on the rotor

Limitation of max. operating pressure (20 MPa)

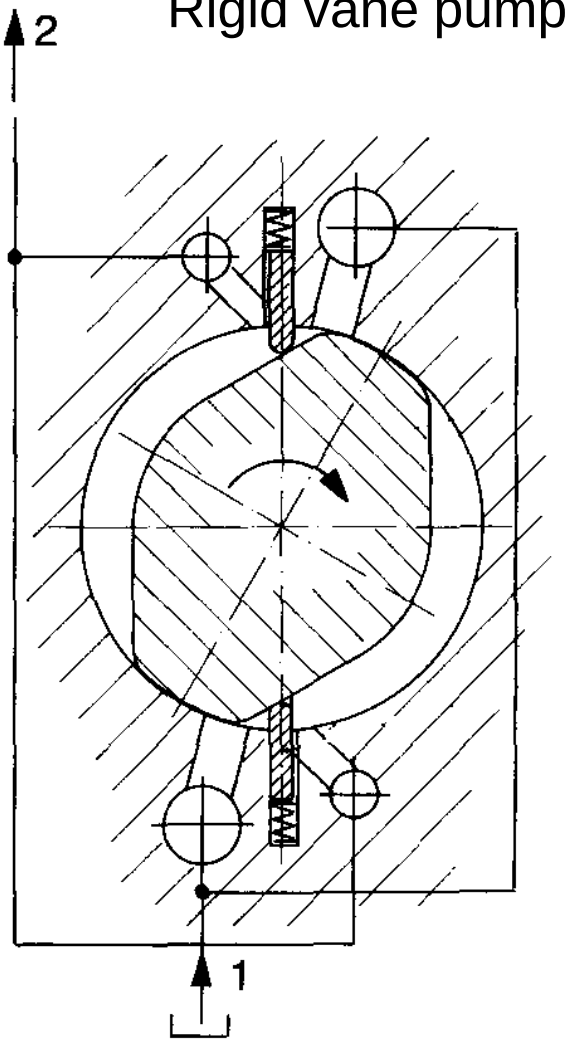
Vane pumps- classification

Multiple stroke vane pump



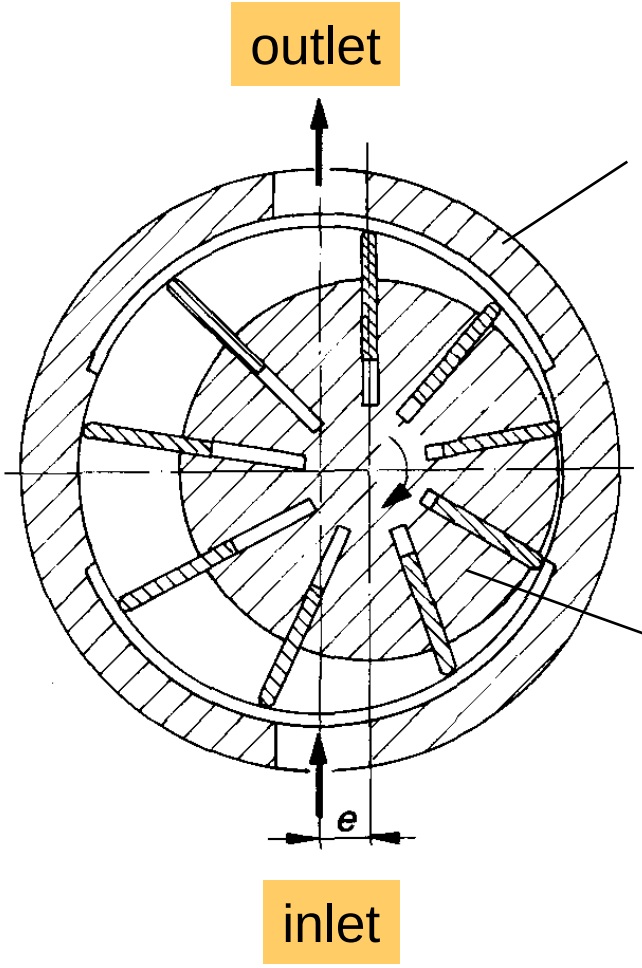
Rotor

Rigid vane pump

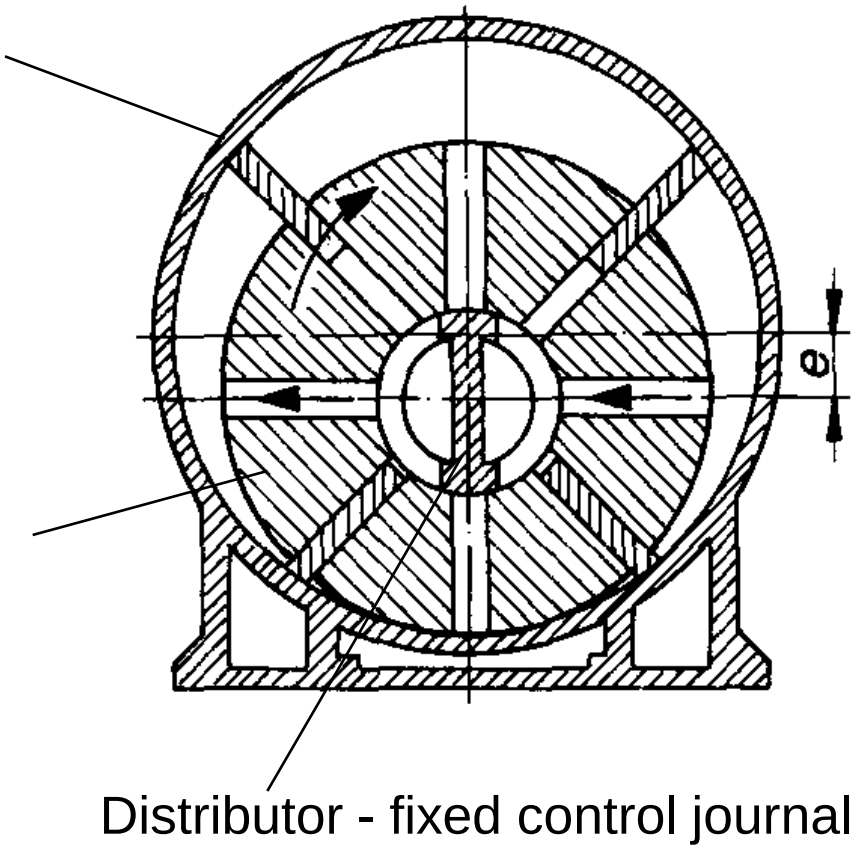


Fluid distribution

External fluid distribution



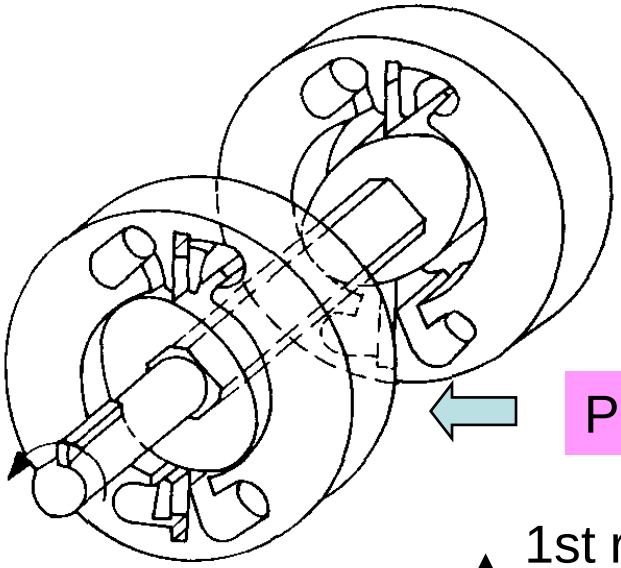
Internal fluid distribution



Rigid vane pump

Displacement volume:

$$V_g = 2 \cdot \frac{\pi \cdot \left(D^2 - d^2\right)}{4} \cdot \frac{180 - \alpha}{180} \cdot b - 2 \cdot \left(\frac{D}{2} - \frac{d}{2}\right) \cdot c \cdot b$$



Pulsation free flow