MENG2520 Pneumatics and Hydraulics

Module 3 – Hydraulic Equipment

-Pumps

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Hydraulic Equipment - Pumps

The pump is key to any hydraulic system providing the hydraulic fluid power

In this Module we will study

- **-Different types of pumps**
- **-Pump performance and selection**

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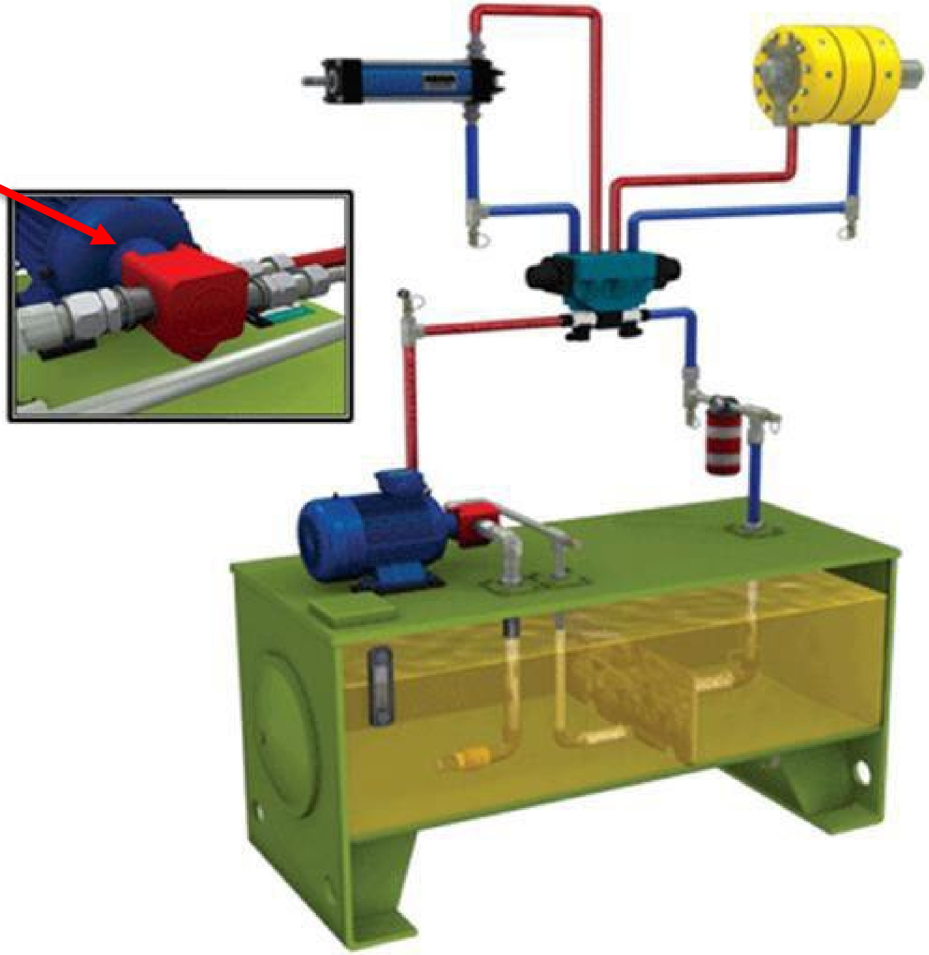
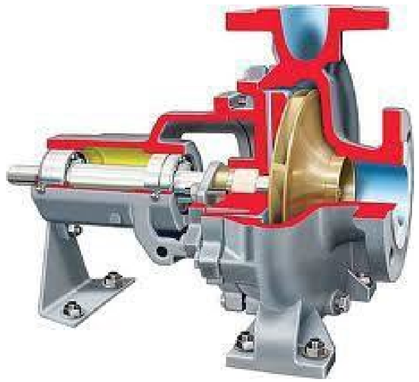
5.1 The Hydraulic Pump

The pump is the heart of a hydraulic system

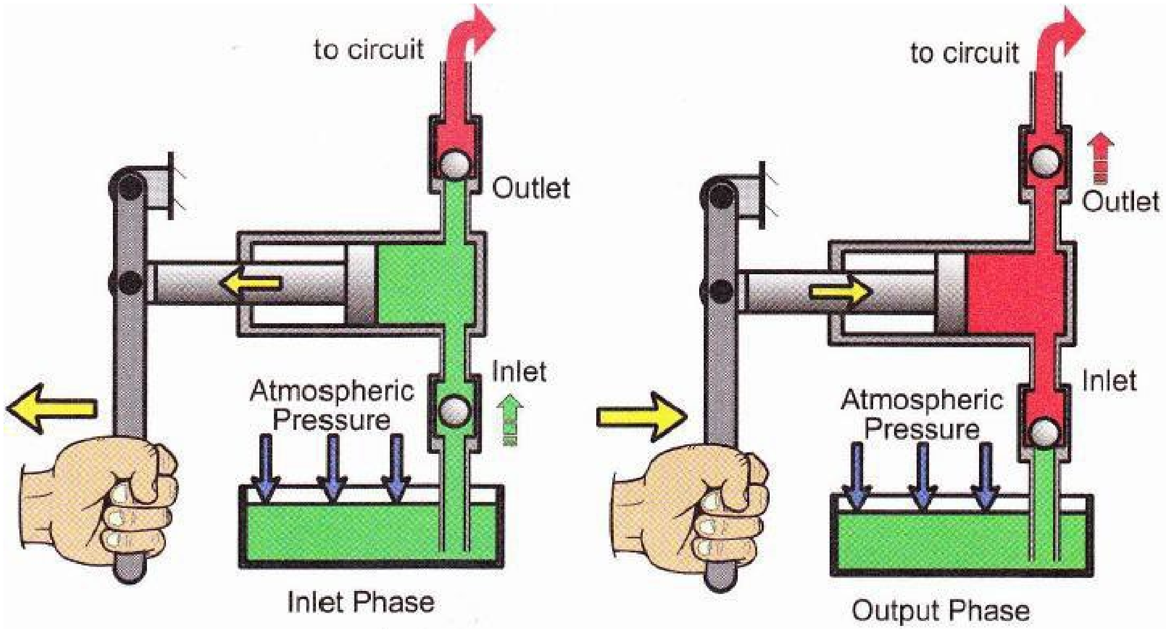
It converts mechanical energy (from a prime mover, e.g. motor) into hydraulic energy.

A partial vacuum is created at its inlet which draws in oil from the tank, and the oil is then pushed into the hydraulic system.





5.3 Hydraulic Pump Operation



1. The Pump internal operation create a vacuum at its inlet.

This allows atmospheric pressure to push the oil from the tank into the pump

2. The pump then, mechanically pushes the oil through the outlet into the hydraulic system.

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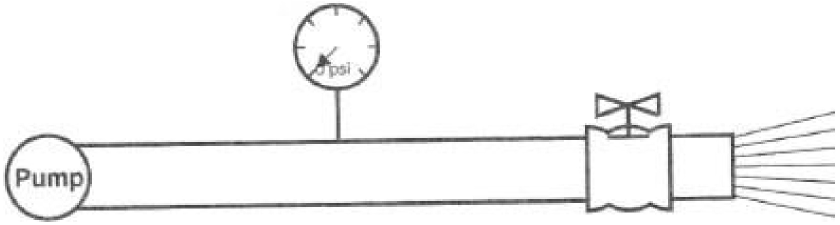
5.3 Flow vs Pressure

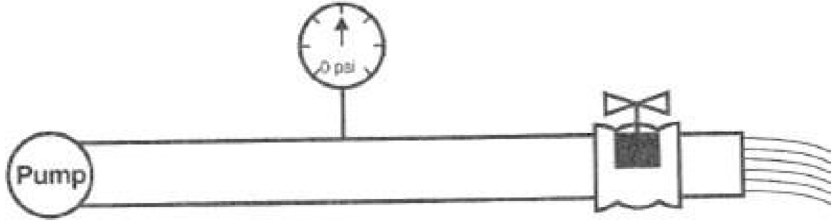
The main function of a pump is to generate “flow” not pressure !



Valve is open

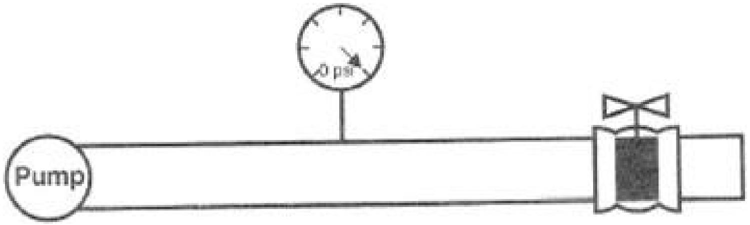
Valve is wide open – large flow and low pressure

Pressure is the result of resistance to oil flow.



Valve is partially closed

Valve closing or closed – lower flow and higher pressure



Valve is completely closed

5.4 Pump Classifications

Displacement is the volume of oil moved from pump inlet to its outlet during each revolution of the pump (in^3/ rev.)

- **Hydraulic Pumps**
  - **Positive Displacement Pumps**
    - Delivers a constant amount of oil in each revolution of operation
    - The typical pump used for hydraulic systems
    - **Fixed Displacement** — The internal pump volume is not adjustable
    - **Variable Displacement** — The internal pump volume is adjustable
  - **Dynamic Non Positive Displacement Pumps**
    - Does not deliver a constant amount of oil in each revolution of operation
    - Flow reduces as pressure increases
    - Can be used for low pressure and high volume applications

Covered in this material

5.4 Pump Classifications

- Hydraulic Pumps
  - Positive Displacement Pumps
    - Gear – Fixed Displacement
    - Vane
      - Fixed Displacement
      - Variable Displacement
    - Piston
      - Axial
        - In line Or Swashplate
          - Fixed Displacement
          - Variable Displacement
        - Bent axis
          - Fixed Displacement
          - Variable Displacement
      - Radial
        - Fixed Displacement
        - Variable Displacement
  - Dynamic Non Positive Displacement Pumps
    - Propeller
    - Centrifugal

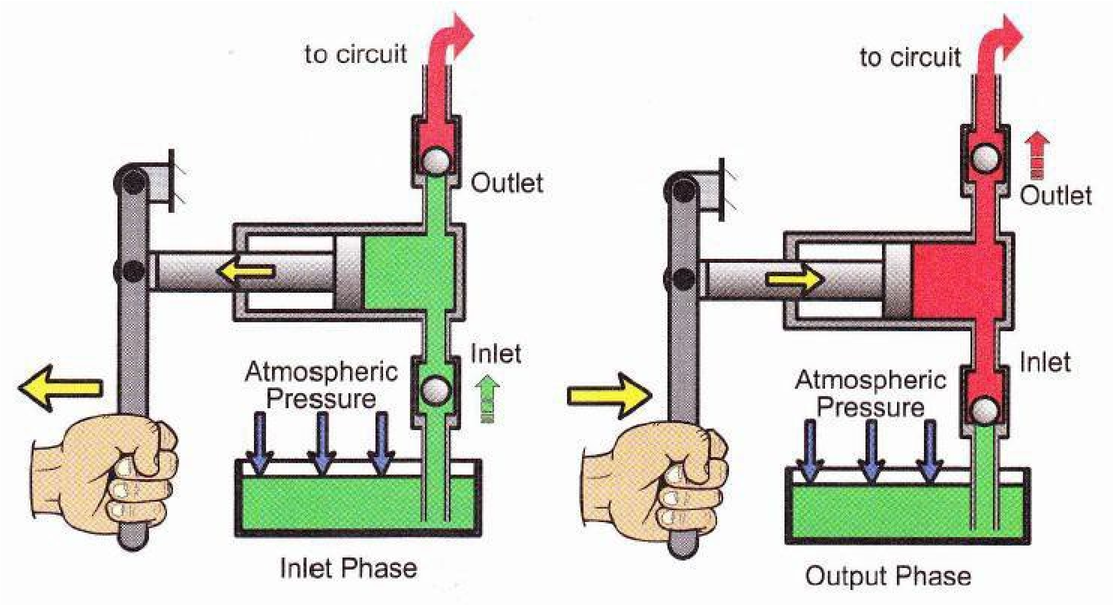
Covered in this material

5.4 Positive Displacement Pumps

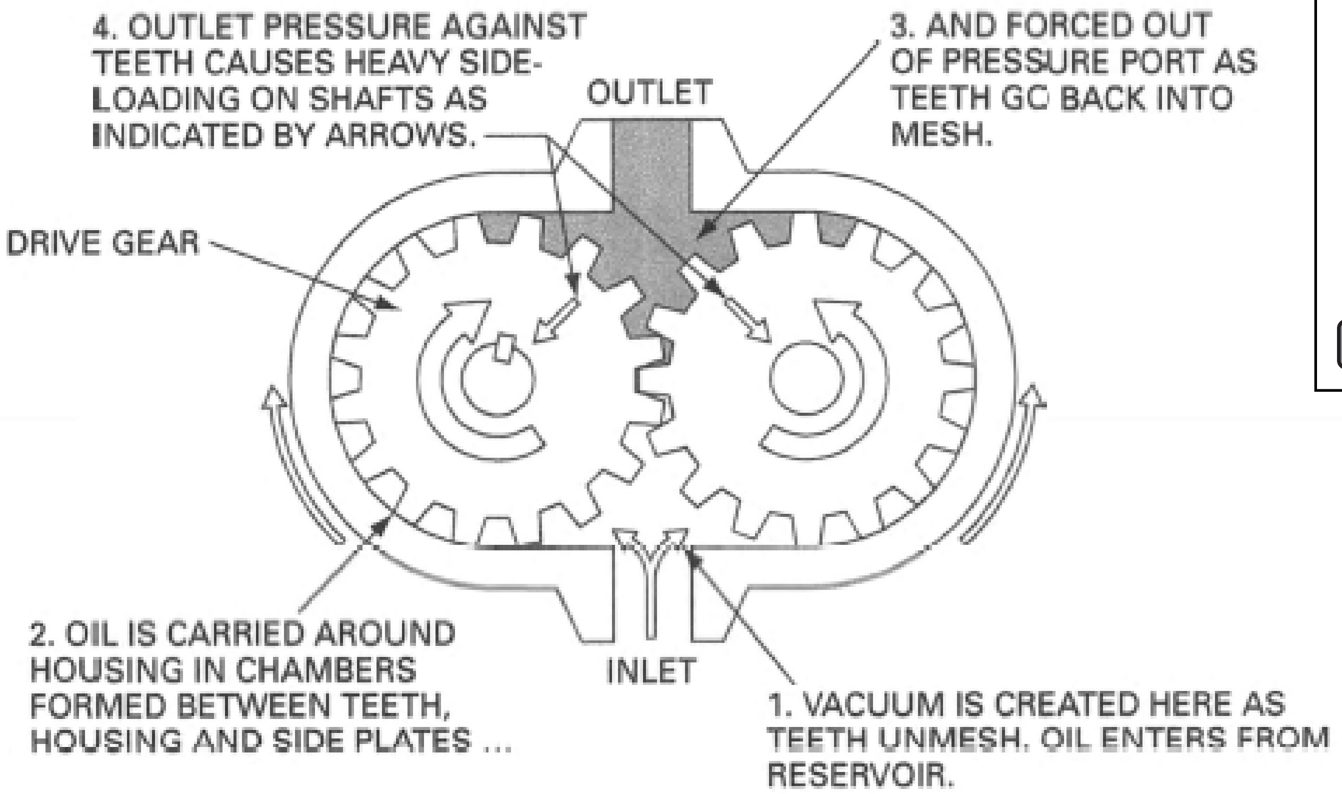
The inlet and outlet sections of the pumping chamber are <u>separated</u> so that the fluid cannot flow back and return to the low pressure side.

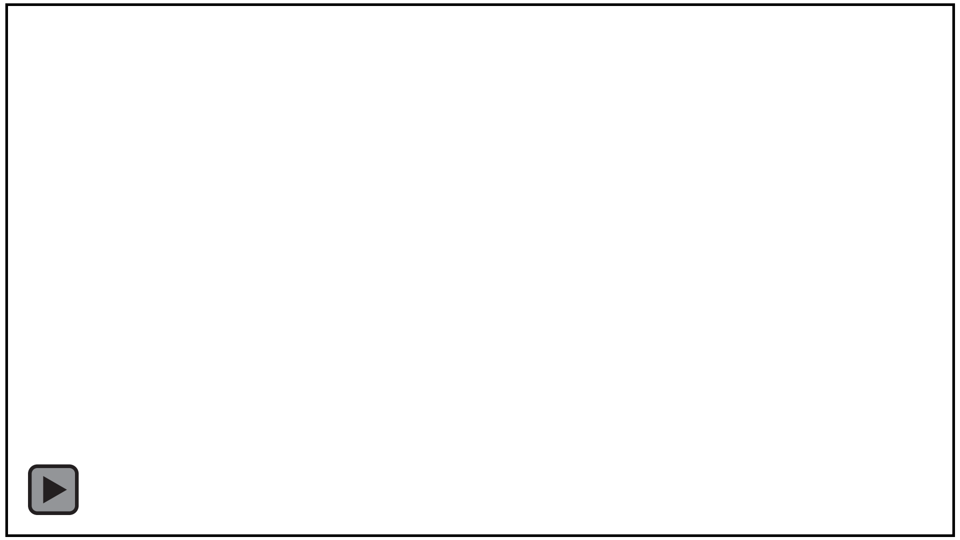
Widely used where the primary consideration is one of power output (medium and high pressure up to 12000 psi)

A pressure relief valve must be used at the outlet to prevent damage to the pump from overpressure if the system resistance increases too much



5.5 Gear Pump – External





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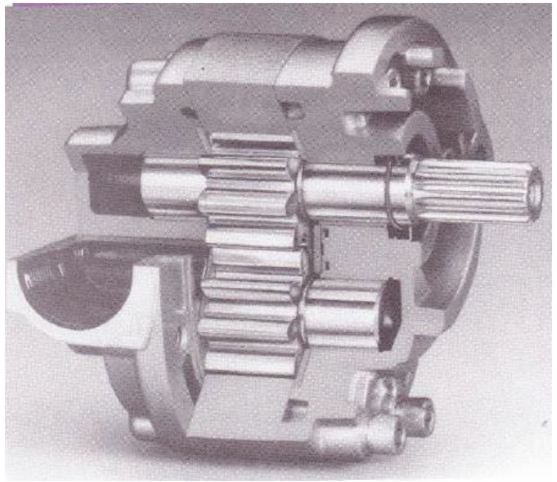
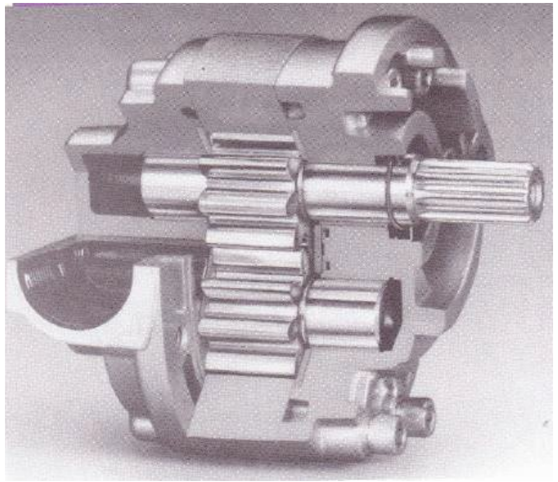


5.5 Gear Pump – External

- Most commonly used pump in hydraulic systems
- Simple and rugged because they have fewer moving parts than other pumps
- Lower pressure than reciprocating pumps
- Lower flow rates than non-positive displacement pumps
- Can handle a wide range of viscosities
- Smooth non pulsating flow
- Highly efficient
- Self priming

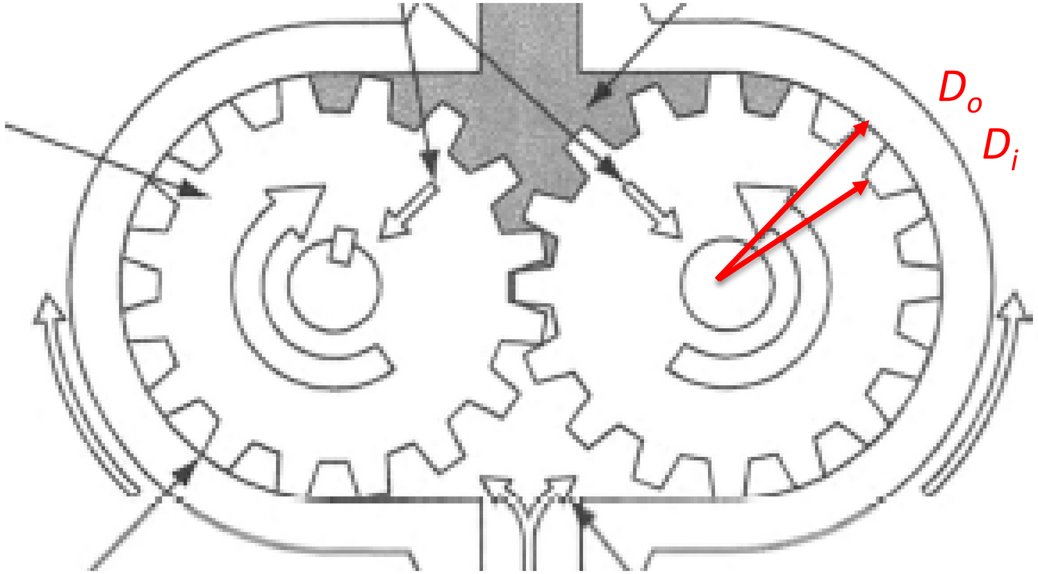


5.5 Gear Pump - External

- The flow rate a gear pump is determined by:
  - i) Volumetric displacement (size of the gears)
  - ii) rotational speed of the prime mover on the driven gear

$$Q_T(\text{in}^3/\text{min}) = V_D(\text{in}^3/\text{rev}) \times N\ (\text{rev/min})$$

$$Q_T(\text{gpm}) = \frac{V_D(\text{in}^3/\text{rev}) \times N(\text{rev/min})}{231}$$



N is the rotational speed

V_D is the volumetric displacement

$$V_D = \frac{\pi}{4}(D_o^2 - D_i^2)L$$

D_o is the outside diameter of the gear

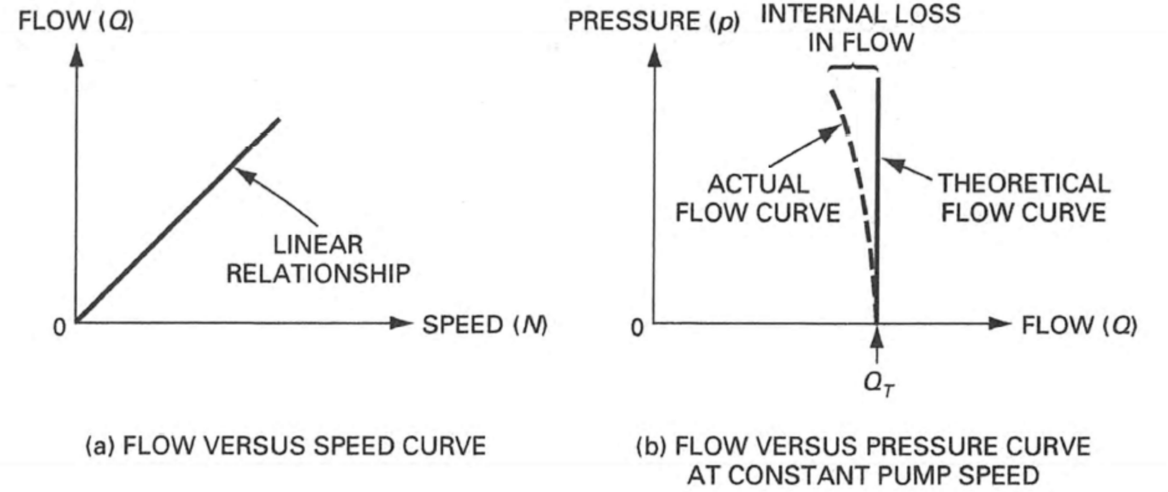
D_i is the inside diameter of the gear

L is the length of the gear

Note: there 2 gears so displacement is x2, but half of the gear volume is occupied by teeth so ÷ 2

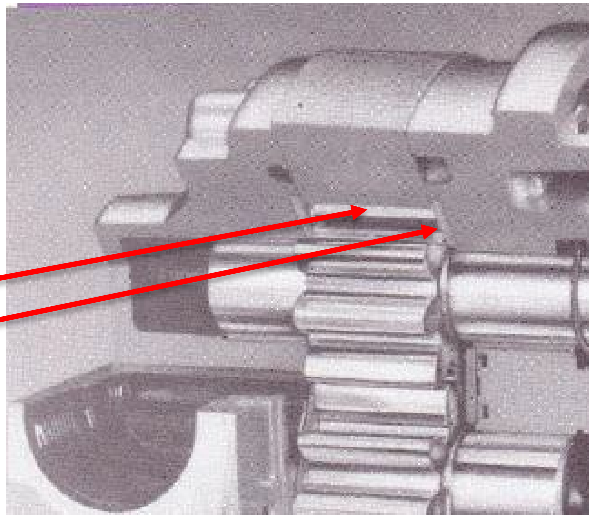
5.5 Gear Pump Efficiency

Flow rate is linear to speed, and thus constant for any given driven speed (neglecting small losses in pump)



(a) FLOW VERSUS SPEED CURVE

(b) FLOW VERSUS PRESSURE CURVE AT CONSTANT PUMP SPEED



Clearance (~0.001 in) between gear and the housing and side wear plates results in a small leakage which increases with pressure

This results in a lost flow rate efficiency, generally around 90%

$$\eta_v = \frac{Q_A}{Q_T}$$

Q_A is actual flow rate

Q_T is theoretical flow rate

5.5 Gear Pump Efficiency

Example: An external gear pump has a 3 in teeth outside diameter, a 2 in teeth inside diameter, and a 1 in teeth width. If the pump run at 1800 rpm and the rated pump flow is 28 gpm, what is the pump volumetric efficiency?

Find the volumetric displacement

$$V_D = \frac{\pi}{4}[(3)^2 - (2)^2](1) = 3.93 \text{ in}^3$$

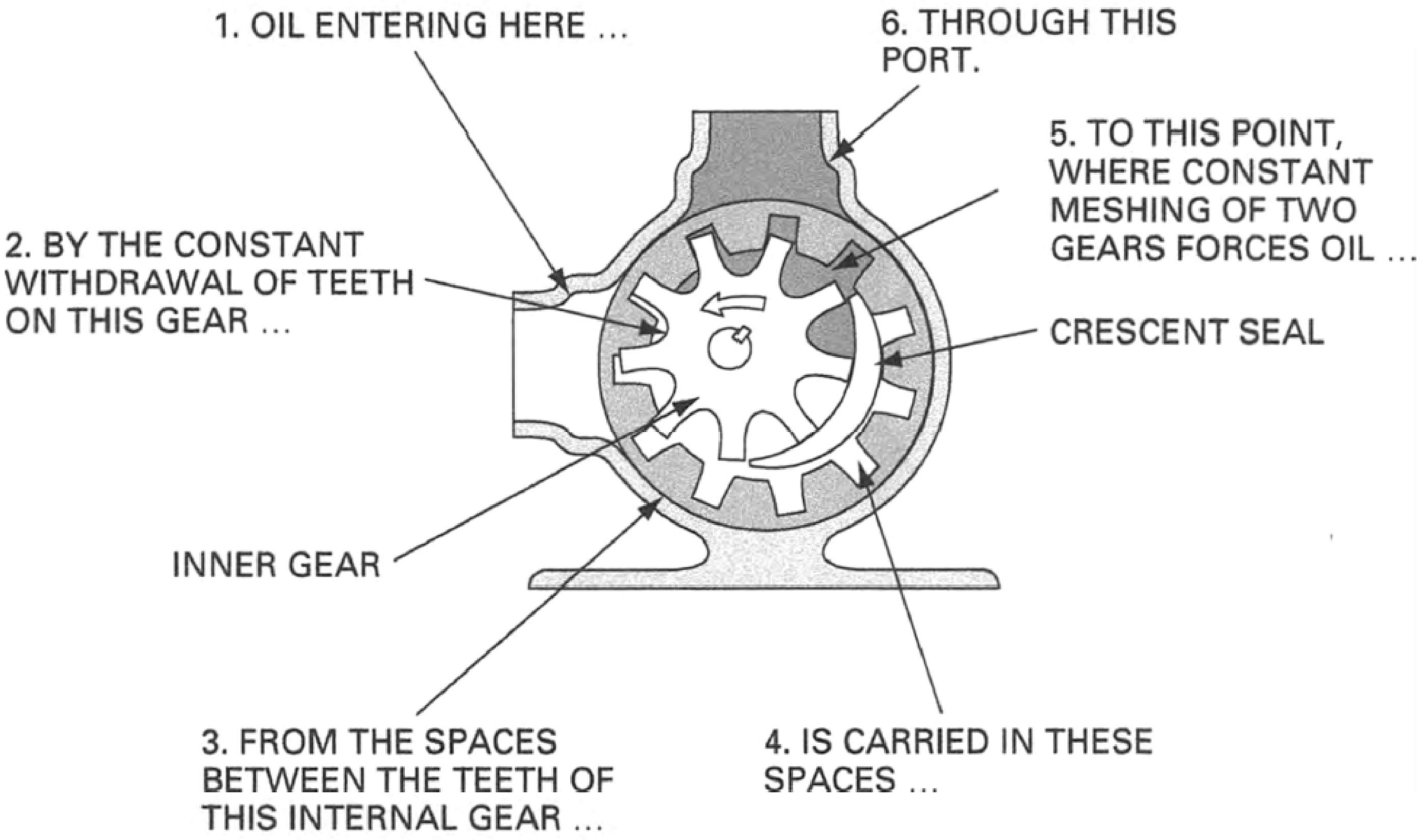
Find the theoretical flow rate

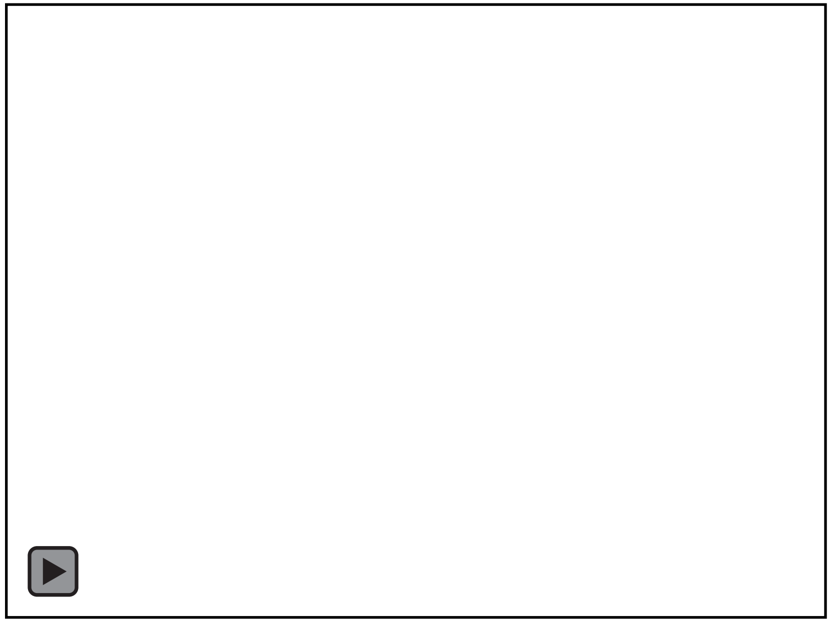
$$Q_T = \frac{V_D N}{231} = \frac{(3.93)(1800)}{231} = 30.6 \text{ gpm}$$

Volumetric efficiency is

$$\eta_v = \frac{28}{30.6} = 0.913 = 91.3\%$$

5.5 Gear Pump - Internal





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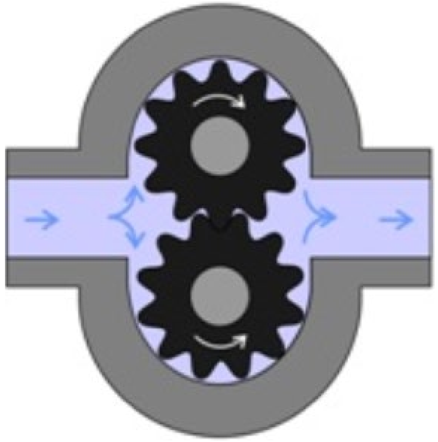
https://pumpschool.com/principles/internal.php

5.5 Gear Pump – External vs Internal

External



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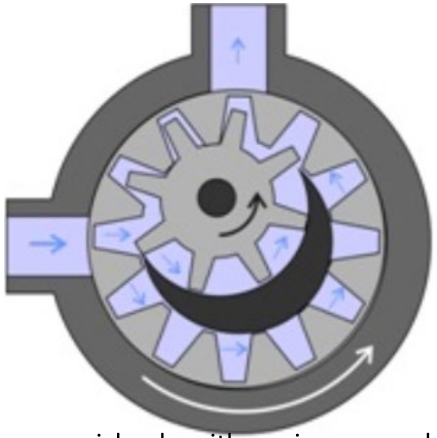
Internal



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- Most used pump in hydraulics
- Non-adjustable
- Low viscosity applications
- Available in very small sizes
- High efficiency at high pressure applications
- Low operating temperature compared to piston and vain

- Versatile
- Can be adjustable
- Very smooth
- High HP for size
- High viscosity applications
- Lower pressure than external
- Less used pump in hydraulics

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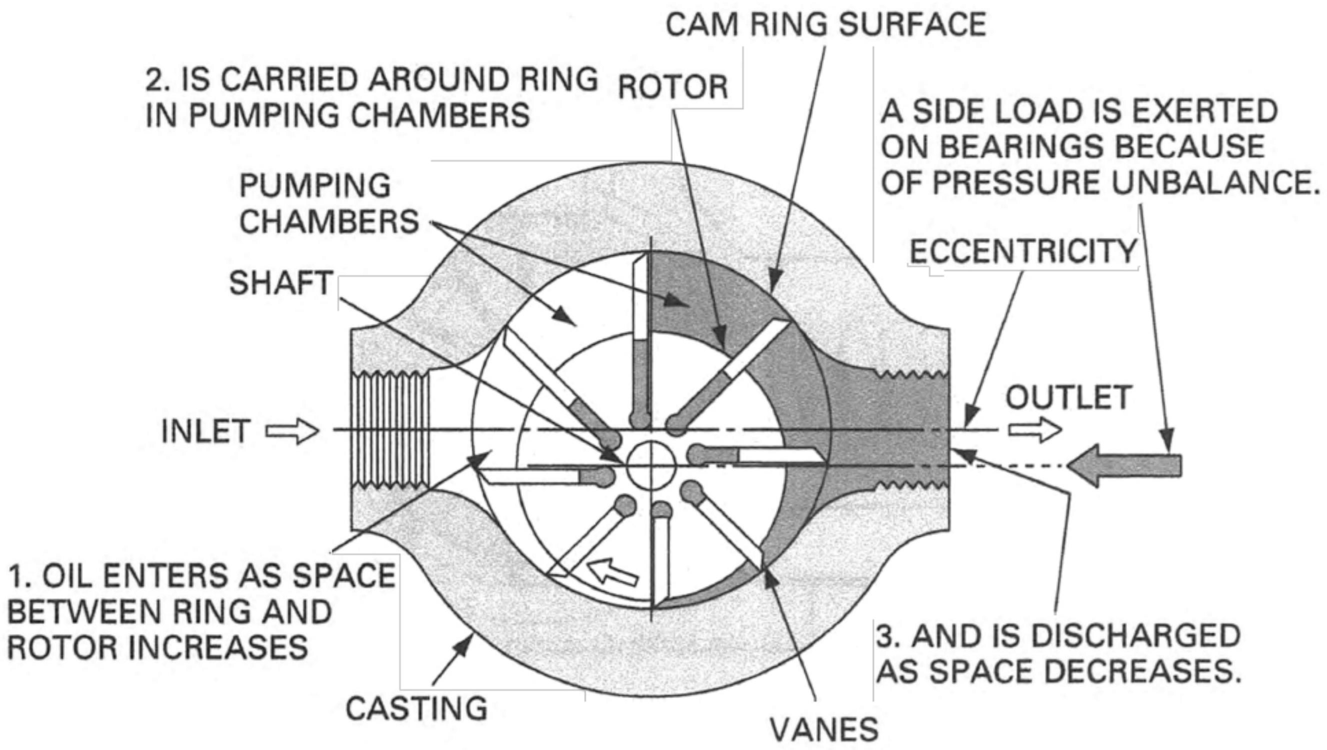
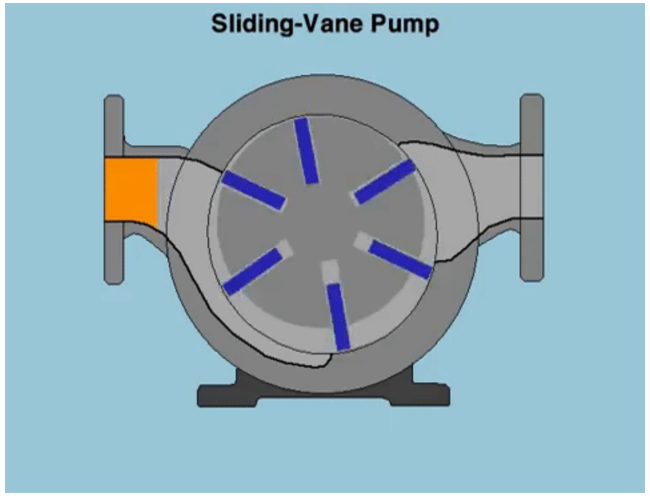
5.6 Vane Pump - Unbalanced





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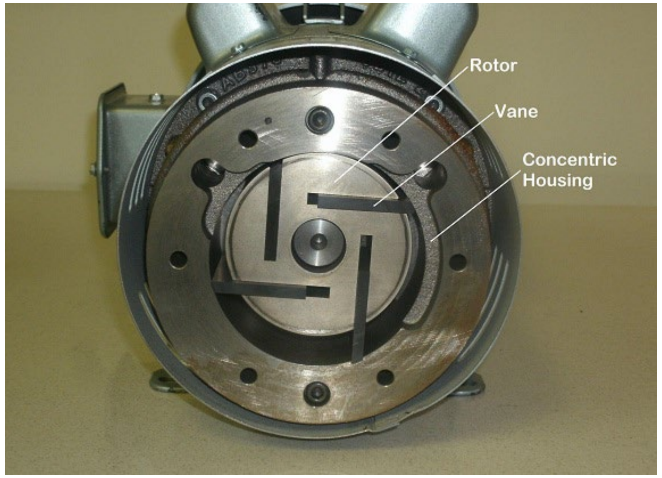

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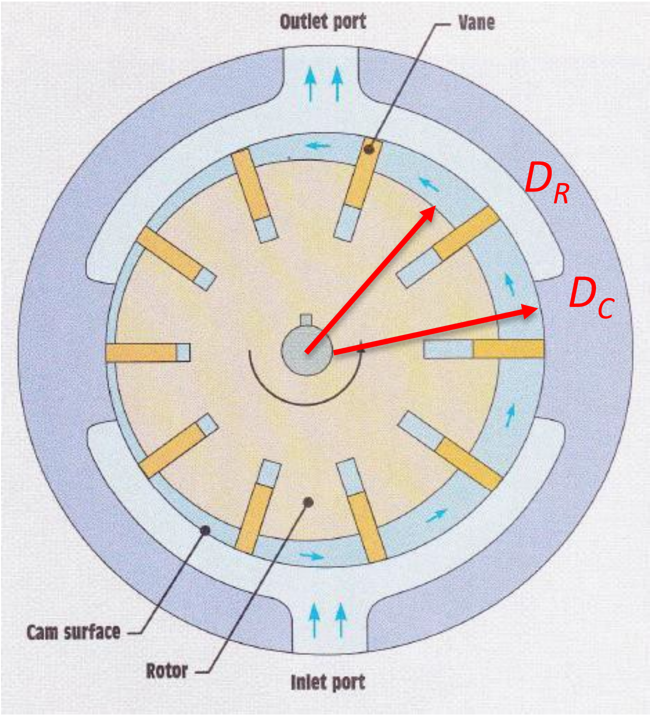
5.6 Vane Pump - Unbalanced

- The flow rate a vane pump, unbalanced, is determined by:
  i) maximum eccentricity of pump
  ii) maximum Volumetric displacement (size of the gears)
  iii) rotational speed of the prime mover on the driven gear

$$Q_T(\mathrm{in}^3/\mathrm{min}) = V_D(\mathrm{in}^3/\mathrm{rev}) \times N\,(\mathrm{rev}/\mathrm{min})$$

$$Q_T(\mathrm{gpm}) = \frac{V_D(\mathrm{in}^3/\mathrm{rev}) \times N(\mathrm{rev}/\mathrm{min})}{231}$$



N is the rotational speed

V_D is the maximum volumetric displacement

$$V_D = \frac{\pi}{2}(D_C + D_R)eL$$

e is the maximum eccentricity $\quad e_{max} = \dfrac{D_C - D_R}{2}$

D_C is the diameter of the cam ring

D_R is the diameter of the rotor

L is the width of the rotor

5.6 Vane Pump - Unbalanced

Example: A vane pump is to have a volumetric displacement of 5 in^3. It has a rotor diameter of 2 in, a cam ring diameter of 3 in, and a vane width of 2 in. What must be the eccentricity?

$$e = \frac{2V_D}{\pi(D_C + D_R)L} = \frac{(2)(5)}{\pi(2 + 3)(2)} = 0.318 \text{ in}$$

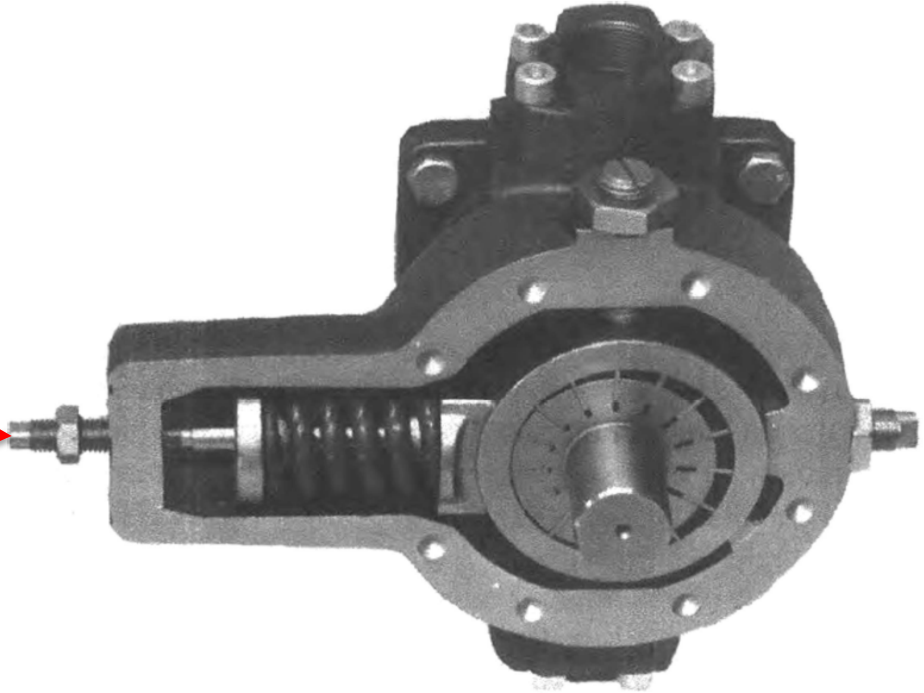
5.6 Vane Pump – Unbalanced, Pressure Compensated

Flow rate (and hence pressure) is determined by the eccentric of the pump

A pressure compensated pump automatically adjusts the eccentricity in response to pressure thus allow the pump to no-flow in the case of exceedingly high pressures

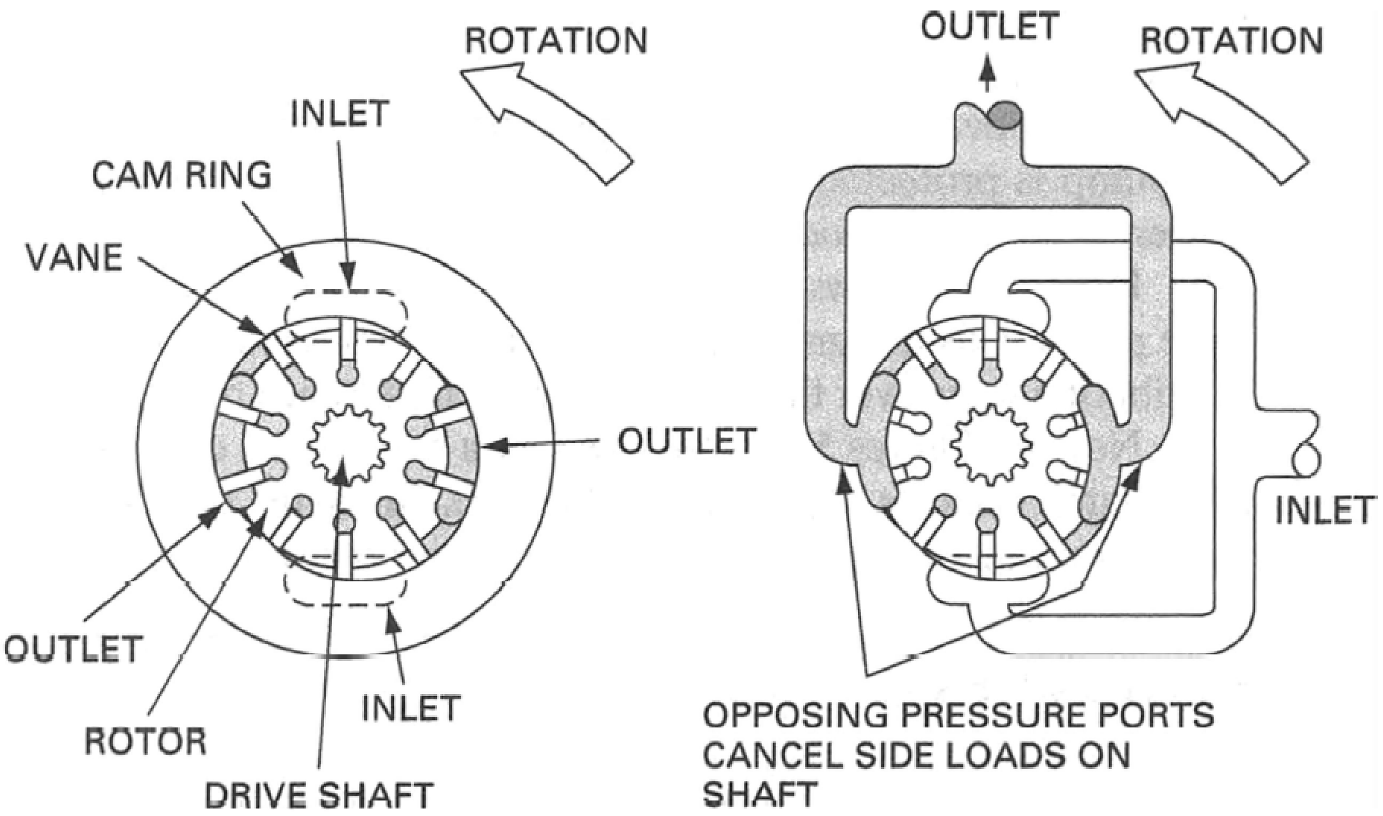
Further adjustments can be made to set max and min eccentricity, thus max and min flow rates

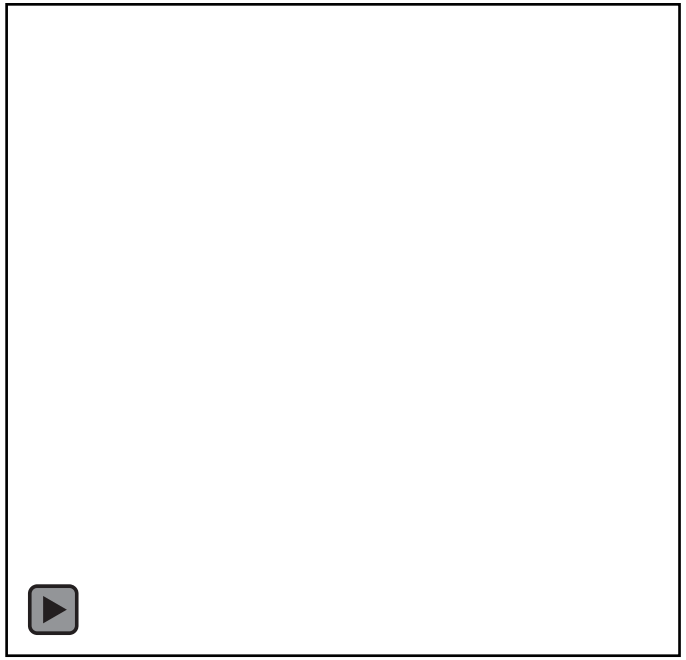
Pressure compensator with adjustment



Maximum displacement adjustment

5.6 Vane Pump - Balanced





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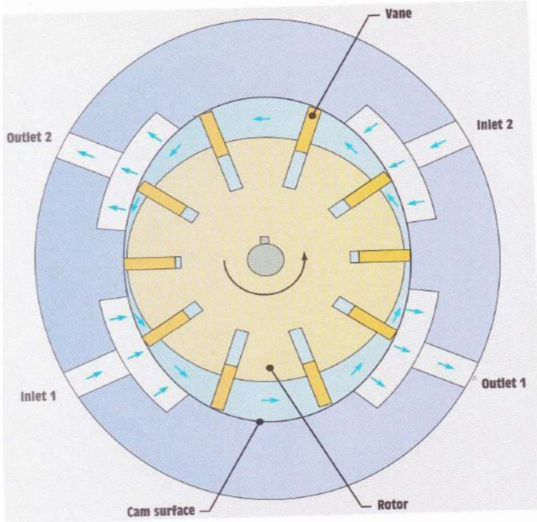
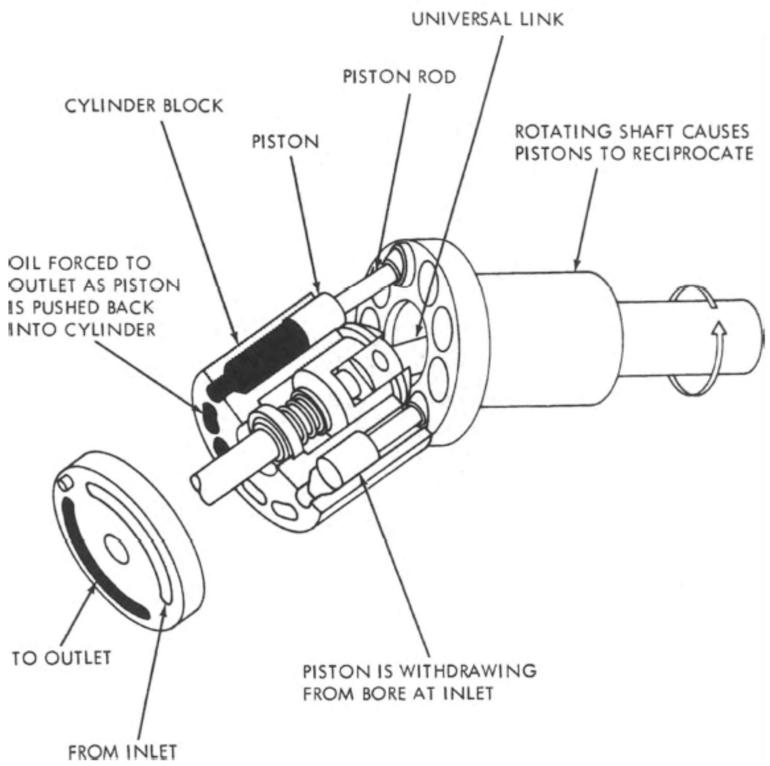


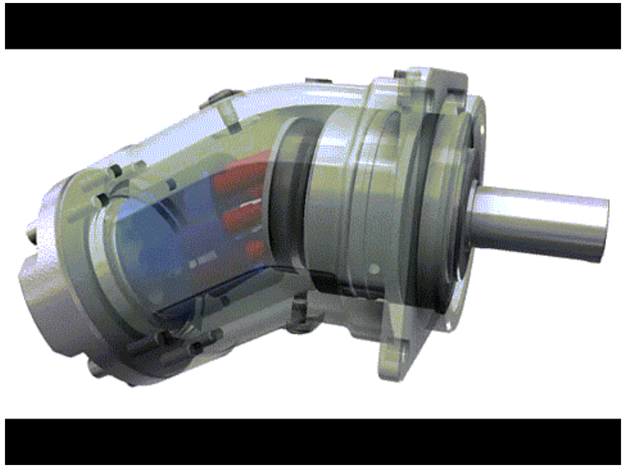
5.7 Piston Pump – Bent Axis



An axial piston pump (bent-axis type) contains a cylinder block rotating with the drive shaft.

The pistons are forced in and out of their bores as the distance between the drive shaft flange and cylinder block changes.

This draws in oil as the piston extends, and the oil is ‘pumped’ out when the piston is retracted.



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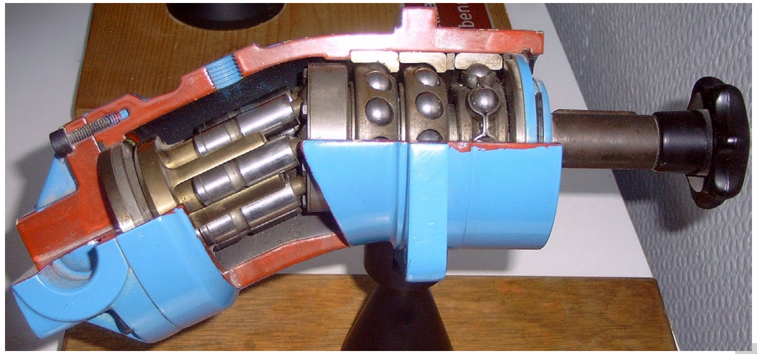

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5.8 Pump Performance

Pump performance is a measure of the efficiency of the pump
How well does the pump convert input mechanical power to hydraulic fluid power

$$overall\ efficiency = \frac{actual\ power\ delivered\ by\ the\ pump}{actual\ power\ delivered\ to\ the\ pump}$$

The overall efficiency η_o is a function of the volumetric efficiency η_v and the mechanical efficiency η_m

$$\eta_o = \eta_v \times \eta_m$$

5.8 Volumetric Efficiency

Volumetric efficiency η_v indicates the amount of leakage that takes place within the pump

Considering factors such as

Manufacturing tolerances

flexing of the pump casing

$$\eta_v = \frac{\text{actual flow-rate produced by pump}}{\text{theoretical flow-rate pump should produce}} = \frac{Q_A}{Q_T}$$

Q_T is the theoretical pump flow rate

Q_A is the actual pump flow rate

<u>Typical Volumetric Efficiencies</u>

Gear pumps	80% - 90%
Vane pumps	82%- 92%
Piston pumps	90%- 98%

5.8 Mechanical Efficiency

Mechanical efficiency η_m indicates the amount of energy loss (other than leakage) that takes place within the pump

Considering factors such as

friction between other moving surfaces (e.g. bearings)

fluid turbulence

$$\eta_m = \frac{\text{pump output power assuming no leakage}}{\text{actual power delivered to pump}}$$

or can be simplified to torque

$$\eta_m = \frac{\text{theoretical torque required to operate pump}}{\text{actual torque delivered to pump}} = \frac{T_T}{T_A}$$

<u>Typical Mechanical Efficiencies are between 90-95%</u>

$$T_T(\text{in} \cdot \text{lb}) = \frac{V_D(\text{in}^3) \times p(\text{psi})}{2\pi}$$

$$T_A = \frac{\text{actual horsepower delivered to pump} \times 63{,}000}{N(\text{rpm})}$$

5.8 Overall Efficiency

$$overall\ efficiency = \frac{actual\ power\ delivered\ by\ the\ pump}{actual\ power\ delivered\ to\ the\ pump} = \frac{brake\ power}{hydraulic\ power}$$

$$\eta_o = \frac{pQ_A/1714}{T_A N/63{,}000} = \frac{\text{actual horsepower delivered by pump}}{\text{actual horsepower delivered to pump}}$$

p is the pump discharge pressure (psi)
Q_A is the pump discharge flow rate (gpm)
T_A is the actual torque applied to pump (in-lb)
N is the pump speed (rpm)

5.8 Overall Efficiency

Example: A pump has a displacement volume of 5 in^3. It delivers 20 gpm at 1000 rpm and 1000 psi. If the prime mover input torque is 900 in • lb,

a. What is the overall efficiency of the pump?

b. What is the theoretical torque required to operate the pump?

a. Use Eq. (5-2) to find the theoretical flow rate:

$$Q_T = \frac{V_D N}{231} = \frac{(5)(1000)}{231} = 21.6 \text{ gpm}$$

Next, solve for the volumetric efficiency:

$$\eta_v = \frac{Q_A}{Q_T} = \frac{20}{21.6} = 0.926 = 92.6\%$$

Then solve for the mechanical efficiency:

$$\eta_m = \frac{pQ_T/1714}{T_A N/63{,}000} = \frac{[(1000)(21.6)]/1714}{[(900)(1000)]/63{,}000} = 0.881 = 88.1\%$$

Finally, we solve for the overall efficiency:

$$\eta_o = \eta_v \eta_m = 0.926 \times 0.881 = 0.816 = 81.6\%$$

b. Using Eq. (5-9) to solve for the theoretical torque we have

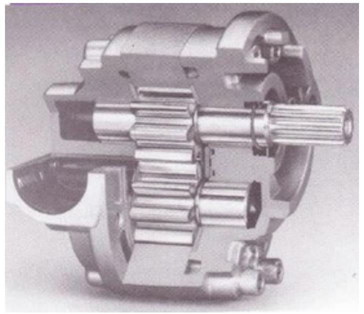
$$T_T = T_A \eta_m = 900 \times 0.881 = 793 \text{ in} \cdot \text{lb}$$

Thus, due to mechanical losses within the pump, 900 in • lb of torque are required to drive the pump instead of 793 in • lb.

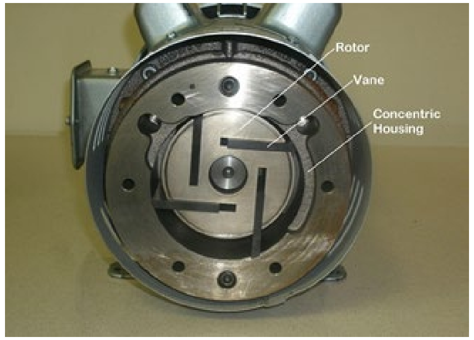
5.10 Pump Selection

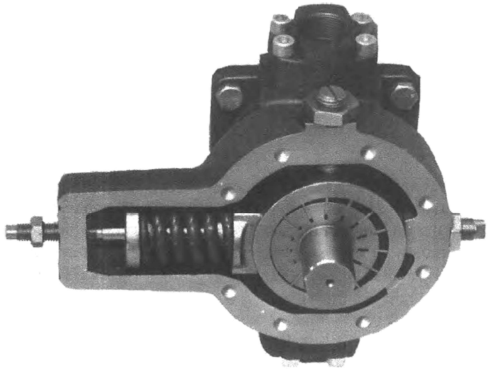
Pumps are selected by taking into account a number of considerations for a complete hydraulic system involving a particular application.

Among these considerations are



Flow-rate requirements (gpm)
Operating speed (rpm)
Pressure rating (psi)
Performance
Reliability
Maintenance
Cost
Noise
Physical size and mounting



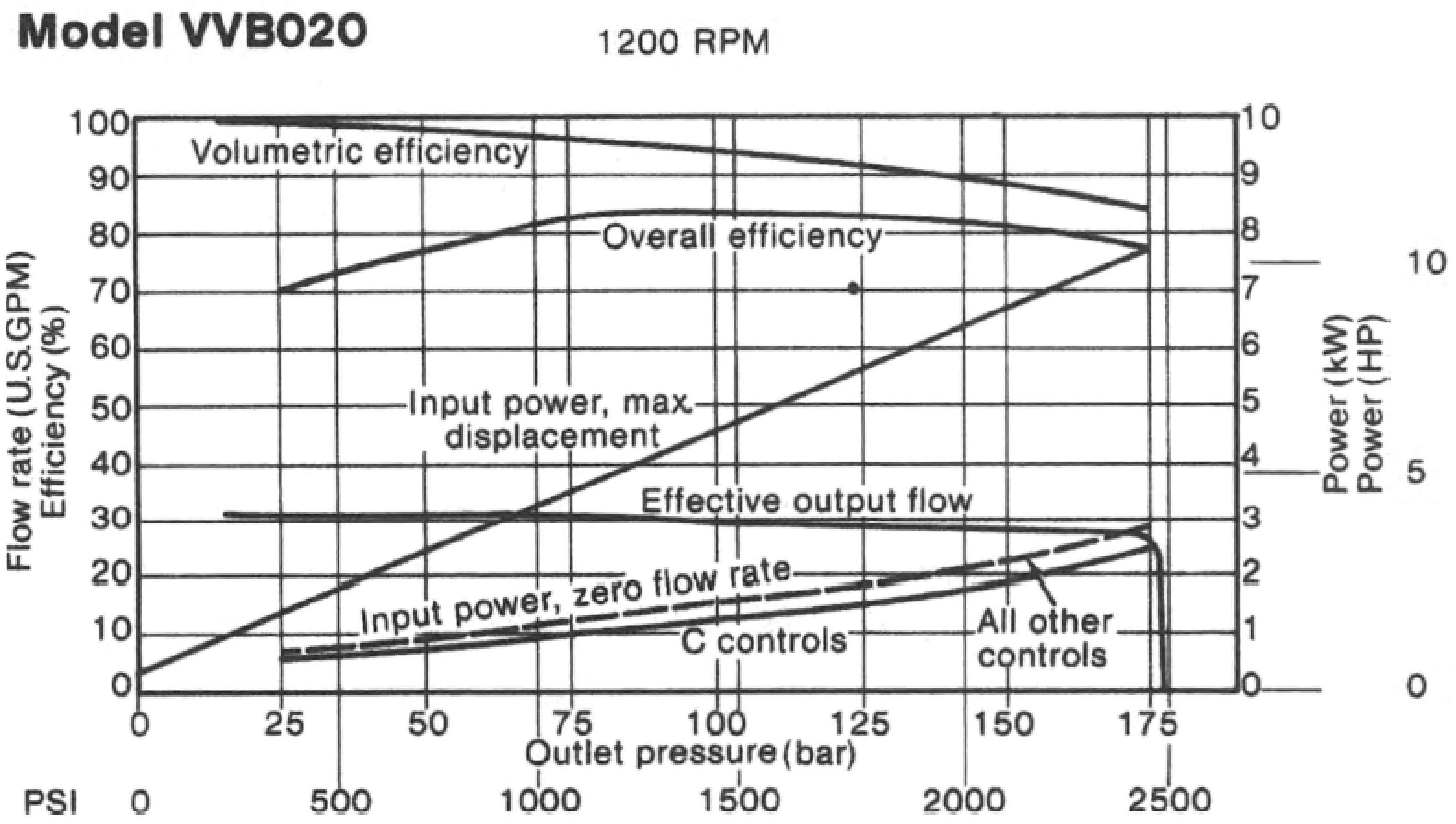


5.10 Pump Selection Procedure

1. Select the actuator (hydraulic cylinder or motor) that is appropriate based on the loads encountered.
2. Determine the flow-rate requirements. This involves the calculation of the flow rate necessary to drive the actuator to move the load through a specified distance within a given time limit.
3. Select the system pressure. This ties in with the actuator size and the magnitude of the resistive force produced by the external load on the system. Also involved here is the total amount of power to be delivered by the pump.
4. Determine the pump speed and select the prime mover. This, together with the flow-rate calculation, determines the pump size (volumetric displacement).
5. Select the pump type based on the application (gear, vane, or piston pump and fixed or variable displacement).
6. Select the reservoir and associated plumbing, including piping, valving, filters and strainers, and other miscellaneous components such as accumulators.
7. Consider other factors such as noise levels, horsepower loss, need for a heat exchanger due to generated heat, pump wear, and scheduled maintenance service to provide a desired life of the total system.
8. Calculate the overall cost of the system.

5.10 Manufacturer's Performance Curves

Performance curves for a variable displacement pressure-compensated vane pump at 1200 rpm



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5.10 Pump Performance Comparison

PUMP TYPE	PRESSURE RATING (PSI)	SPEED RATING (RPM)	OVERALL EFFICIENCY (PERCENT)	HP PER LB RATIO	FLOW CAPACITY (GPM)	COST (DOLLARS PER HP)
EXTERNAL GEAR	2000–3000	1200–2500	80–90	2	1–150	4–8
INTERNAL GEAR	500–2000	1200–2500	70–85	2	1–200	4–8
VANE	1000–2000	1200–1800	80–95	2	1–80	6–30
AXIAL PISTON	2000–12,000	1200–3000	90–98	4	1–200	6–50
RADIAL PISTON	3000–12,000	1200–1800	85–95	3	1–200	5–35

5.10 Pump Type Comparison

Parameter	Gear pumps	Vane pumps	Piston pumps
Design	Simple, rugged	Slightly complex	Complex
Displacement type	Fixed	Fixed or variable	Fixed or variable
Pulsation	High	Low	High
Fluid sensitivity	Least sensitive	Sensitive	Sensitive
Effect of contaminants	Tolerant	Less tolerant	Sensitive
Leakage	Prone to leakage	Less prone	Prone to leakage
Noise level	High	Low	High
Size	Small to medium	Small to medium	Medium to large
Power-to-weight ratio	Low	Low	High
Efficiency	Least	Medium	Highest (>90%)
Cost	Cheapest	Medium	Costly
Maintenance costs	High, due to wear	High, due to wear	Very high
Service life	Longest	Long	Very long
Application	Light-, medium-duty	Light-, medium-duty	Heavy-duty
Pressure level	Medium	Lowest	Highest
Displacement	Medium	Lowest	Highest
Viscosity range	highest	Low	Low

https://www.academia.edu/33032852/Hydraulic_Pumps_Comparison

Chapter Reading

Chapter 5

5.2, 5.7, 5.9, 5.11