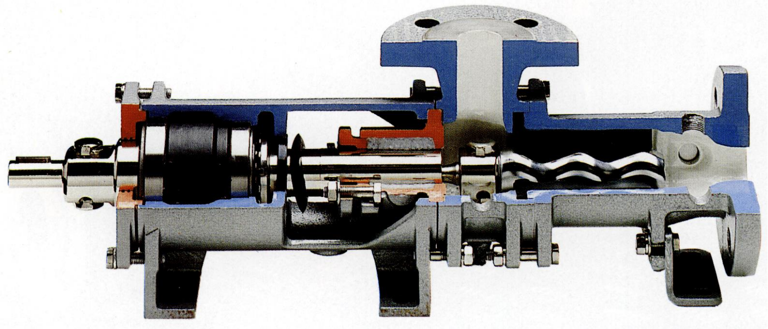
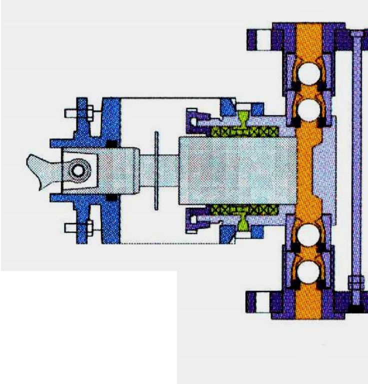
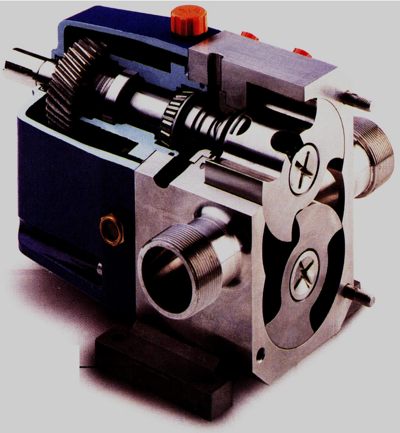



Positive Displacement Pumps

1. Rotary
2. Reciprocating
3. Miscellaneous




Positive Displacement Pumps (i)

The positive displacement pump displaces forcibly specific volumes of liquid against the system resistance. The system resistance directly affects the pump delivery pressure which will keep on rising until the delivery pressure matches the system or until the driver or the pump is overloaded. For this reason these pumps must be provided with relief valves either in the pump or directly after the pump in the delivery line to provide the necessary protection.

The forcible displacement of specific volumes makes the flow rate dependent theoretically on the pump speed and geometry. In practice there is always leakage through the necessary clearances between the moving and stationary wetted components. Thus the head capacity curve is a substantially flat line showing a small capacity reduction with increasing differential pressure or head rise.

Positive Displacement Pumps (ii)

There are many types of positive displacement pumps. These can be classified under three main categories depending on their construction.

1. Rotary
2. Reciprocating
3. Miscellaneous

The rotary pump forcibly transfers liquid from suction to discharge by the action of rotating pumping elements operating in a container of fixed volume.

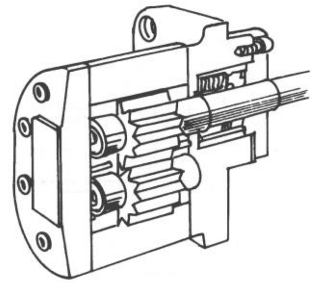
The reciprocating pump forcibly transfers liquid from suction to discharge by the action of a reciprocating (piston) or oscillating member (diaphragm) in a container the available pumping volume of which varies from a very small to its maximum value according to the position of the pumping element.

The miscellaneous pump forcibly transfers liquid from suction to discharge by a combined rotary and reciprocating action causing the volume containing the pumped liquid to vary from a small value to its maximum.

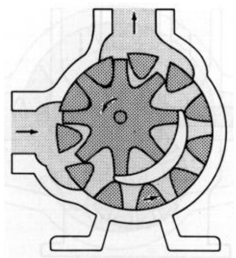
Rotary Positive Displacement Pumps

Rotary pumps may be classified according to their construction in the following categories.

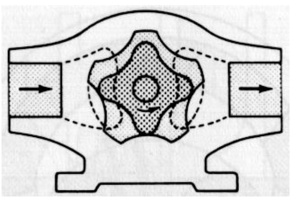
1. External Gear
2. Internal Gear
3. Lobe
4. Screw
5. Eccentric Helical Rotor (Moineau Type)



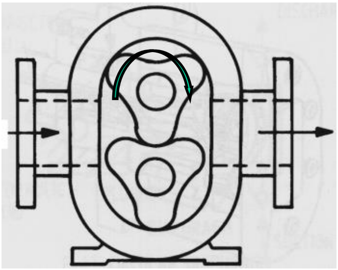
1



2a With Crescent



2b without Crescent



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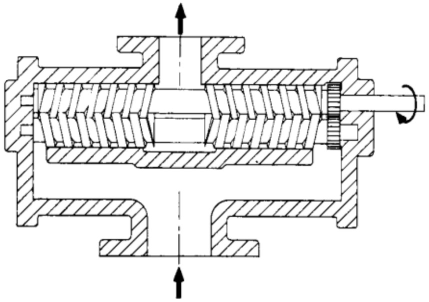
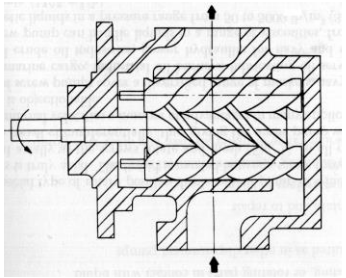
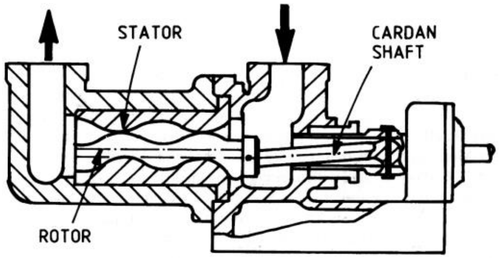






5

Gear Pumps (i)

The casing of gear pumps contain two gear wheels (spur or helical or herring bone type teeth) meshing together either externally (external gear pumps) or internally (internal gear pumps).

The simplest type has a driving gear and a follower but precision machines or those handling low lubricity liquids or liquids with some small solids in suspension have a set of driving gears in an external gearbox to provide mechanical drive and maintain a fixed fine clearance in the meshing zone of the pumping gears.

Liquid is picked up from the suction port in the space between the gear teeth and delivered to the outlet port in fixed steady amounts with pulsations at a frequency depending directly on the number of teeth and the rotational speed of the gears. Thus gear pumps have small, possibly negligible operating fluid pulsations.

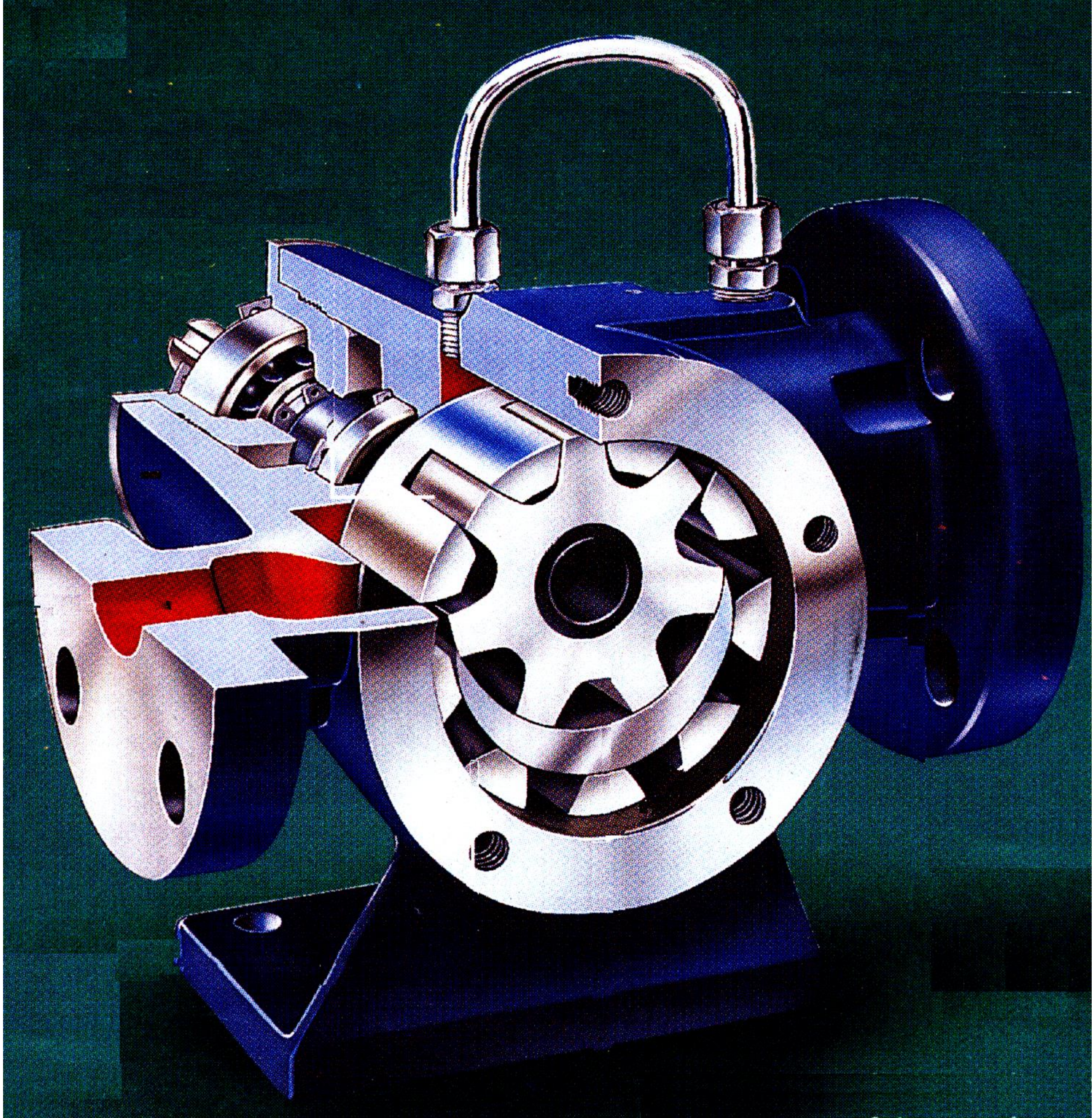
Gear Pumps (ii)

Close clearances are essential for maintaining low internal leakage and so high volumetric efficiencies. However close internal clearances make the pump susceptible to external piping loads and coupling misalignment. Internal and external gear pumps have many similarities. However the internal gear pump in general have lower pressure and volume ranges and less liquid turbulence.

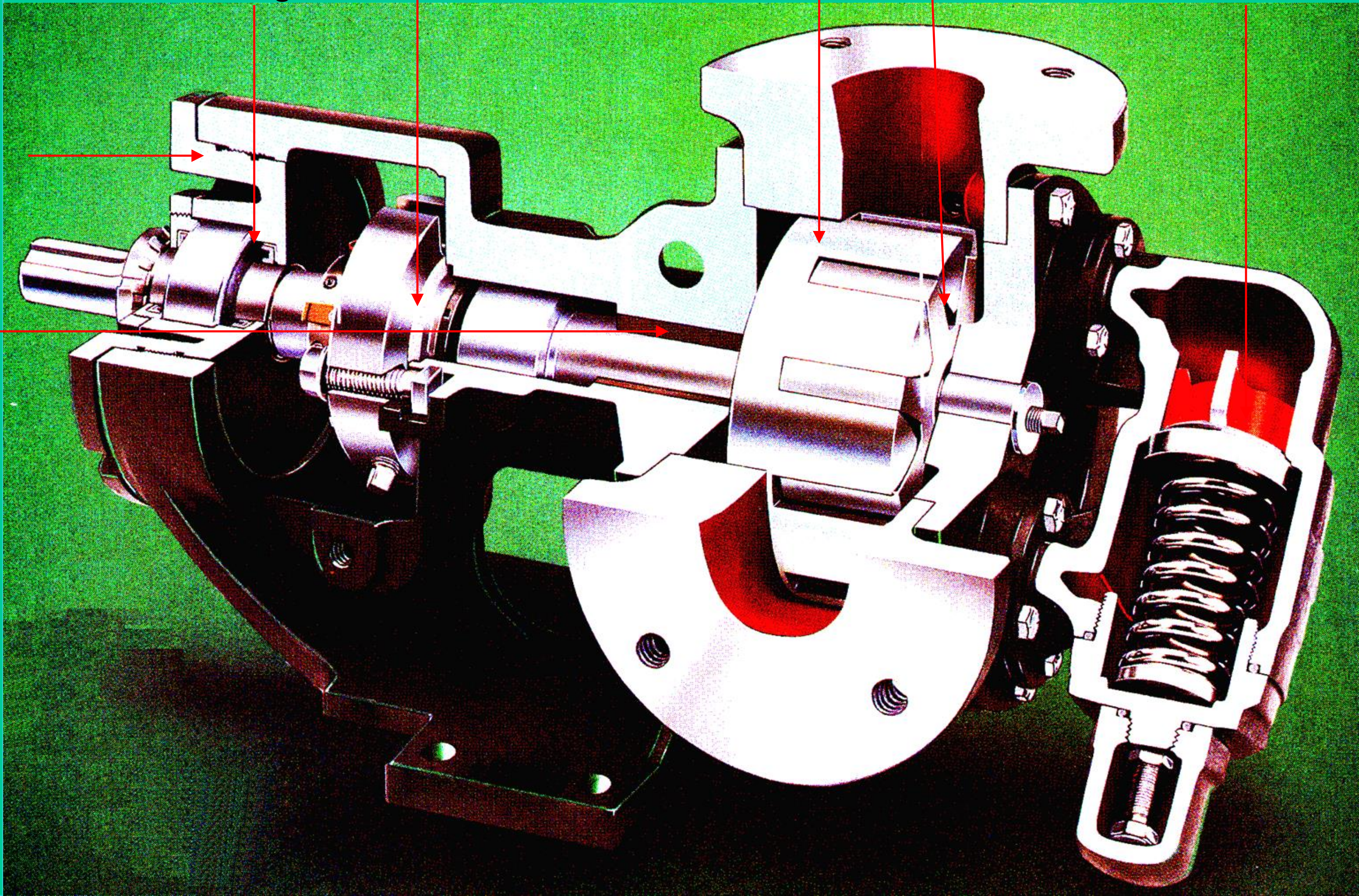
The pressure distribution at the periphery of the gears creates radial thrusts on the gears and their shafts, the higher the discharge pressure the higher the radial thrusts. Therefore the shafts must be of generous dimensions and have good heavy load supports. On the other hand axial thrusts are practically balanced.

Gear pumps with close clearances are self priming since the rotating gears can evacuate gases from the suction system.

Internal Gear Positive Displacement Pump



Internal Gear Pump Section



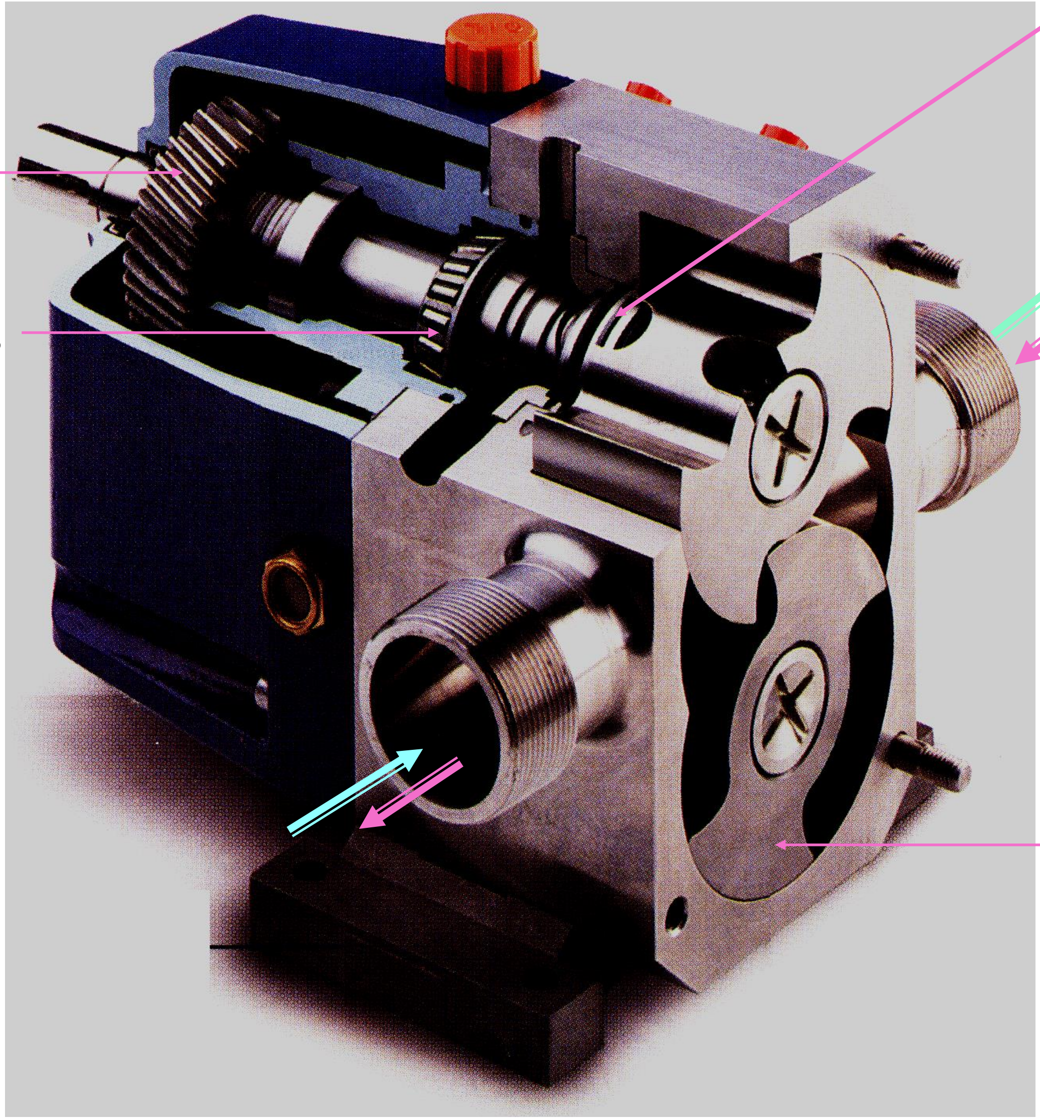
Lobe Pumps

Lobe pumps are identical in concept with the external precision gear pump as the action of the gears is taken by two rotors with two, three or even four lobes powered by an external gearbox. Because the liquid is delivered in a much smaller number of larger quantities, than in the gear pump, the liquid pulsations at discharge are more pronounced.

In some pumps the lobes are fitted with replaceable sealing strips. The wear on the lobes is less, the internal clearances between lobes and casing less critical and the coupling alignment similarly so.

Lobe pumps are not as expensive as the corresponding gear pumps. Moreover they can be easily steam purged and cleaned and they therefore find extensive application in the food and pharmaceutical industries.

Twin Lobe Pump



Screw Pumps

Screw pumps can deliver high flow rates and develop high heads.
There are pumps with two or three rotors.

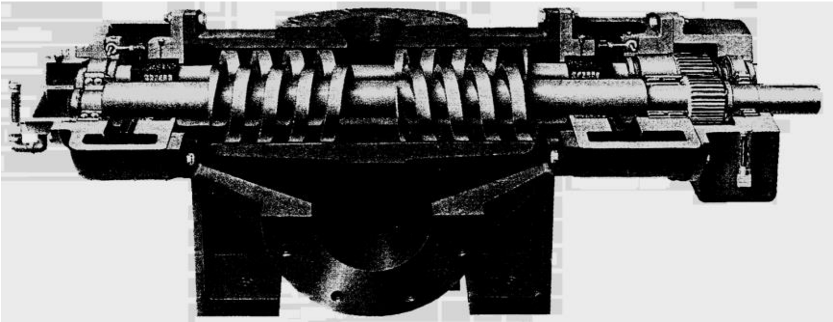
In the majority of cases the rotors are carefully matched together with very close clearances to achieve high volumetric efficiencies. When the rotors have precision clearances they are powered by a timing gearbox driving each rotor to ensure that the rotors do not touch each other and that a fine clearance is maintained between them. This timing gearbox can be either internal or external depending on the lubricity and cleanliness of the pumped liquid.

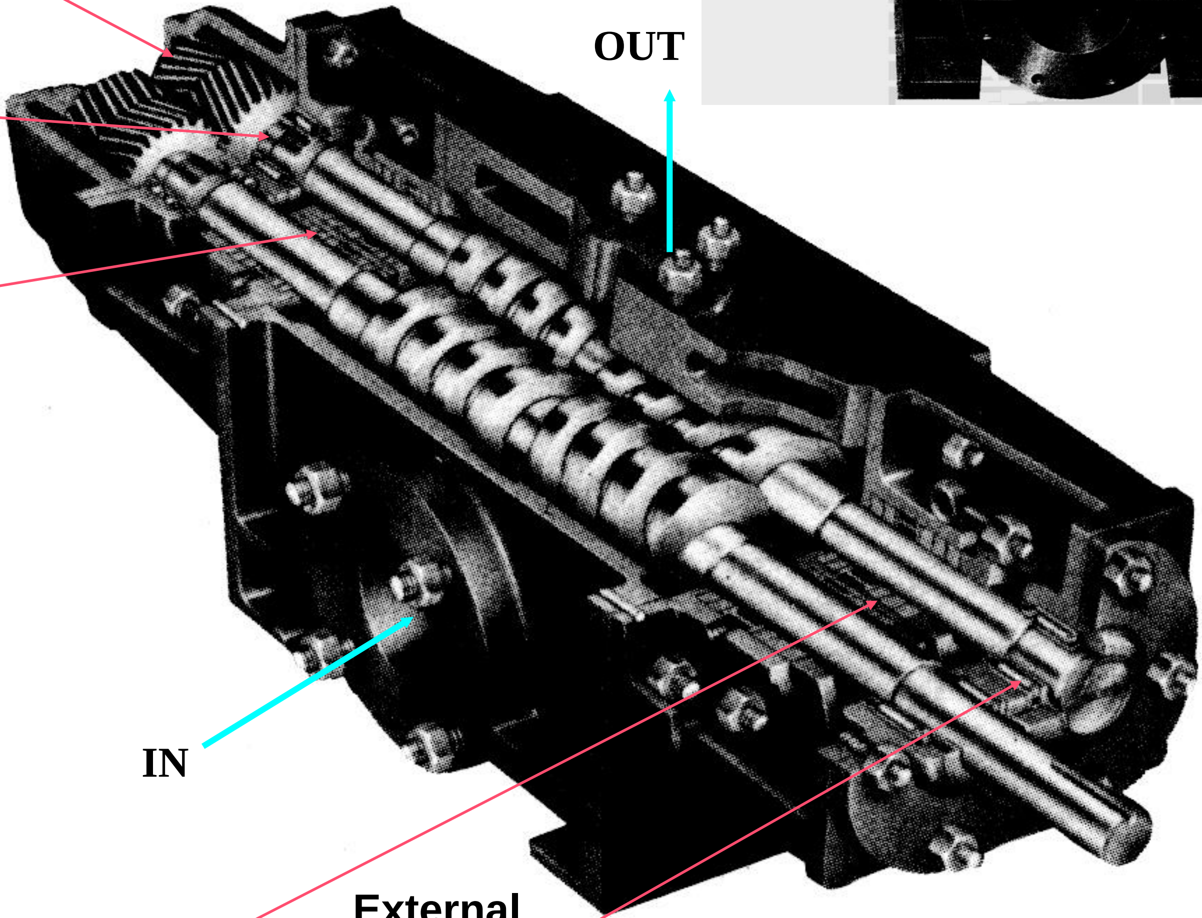
The flow is practically pulsation free.

Liquid viscosity affects the flow rate but fairly high viscosities can be dealt with.

No suction or discharge valves are required but a relief valve at discharge is essential.

Two Rotor Screw Pump





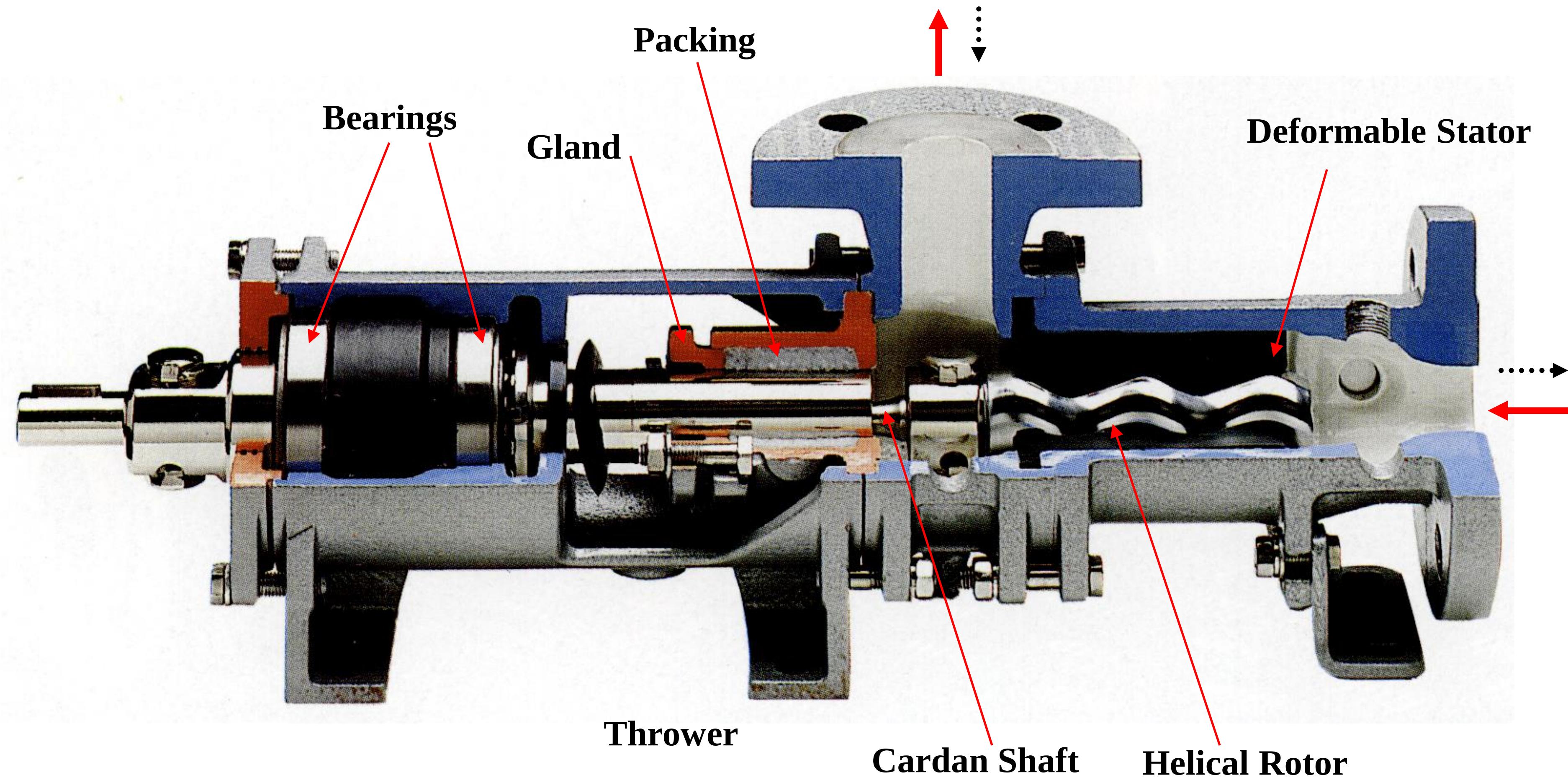
Eccentric Helical Rotor

The eccentric helical rotor (Moineau Type) pump has a helical rotor which runs with an interference fit in a deformable stator. The stator has a double helix cut corresponding to that of the solid rotor. The rotor axis follows a circular path hence the need for cardan shaft which can transmit the motion to the eccentric rotor.

The stator is made of a deformable material such as natural or nitrile rubber while the rotor is made of chrome plated steel, or stainless steel or nitralloy or other such corrosion and abrasion resisting metallic material depending on the duty. The assembly due to the interference fit must never be run dry.

The design is self priming and self sealing and does not need suction or discharge valves. It can handle viscous, sludgy materials with suspended solids. The pressure that can develop depends on the number of helical convolutions and so the length of the rotor.

Eccentric Helical Rotor Pump



Reciprocating Pumps (i)

Piston or Plunger Type.

Both types function because of the reciprocating (back and forth) motion of a solid “plug”drawing the liquid in a cylinder through a suction non return valve and then forcing it out on the return stroke through the discharge non return valve. When this reciprocating “plug” has one side in contact with the liquid and its other end which is connected to the driving mechanism has a seal to prevent the liquid escaping is termed a plunger. If this plug has two sides exposed to the pumped liquid and seal rings between these two parts to seal the liquid between the sides it is termed a piston. The seal which separates the pumped liquid from the atmosphere operates on the rod driving the piston. In addition the piston is double acting i.e while one side is drawing liquid in the cylinder the other side is discharging. The plunger is single acting.

The driving mechanism is one that translates rotary motion (that of the driver) to a reciprocating motion (that of the piston or plunger). It is either a crank mechanism or an eccentric. In certain instances it is a direct acting reciprocating drive such as a steam engine.

Reciprocating Pumps (ii)

Diaphragm Type

Diaphragm type reciprocating pumps have an oscillating diaphragm that crates the pumping action on the process liquid. The oscillating motion of the diaphragm is either by oscillating fluid pressure created by a plunger acting on a hydraulic couplant liquid or less frequently by direct mechanical connection of a reciprocating member to the diaphragm.

In certain cases the diaphragm can be actuated by pulsating air flow. Compressed air is admitted to and vented from the drive side of the diaphragm of the pump.

Diaphragm pumps are self priming. They can handle liquids containing vapours and gases or a substantial amount of solids or liquids of high viscosity. In all such cases the pump valves must be carefully selected for the particular service.

Diaphragm pumps are used especially for handling polluting, odorous or toxic fluids since the diaphragm positively separates the pumped liquid from the environment

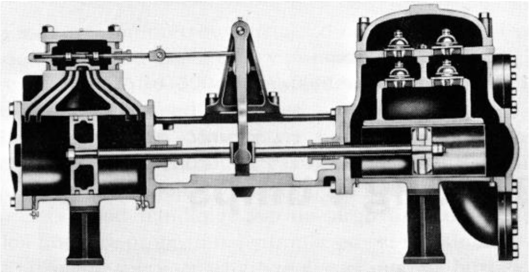
Reciprocating Pumps

Similarly reciprocating pumps may be classified into:-

1. Piston or Plunger

Direct Acting Pump

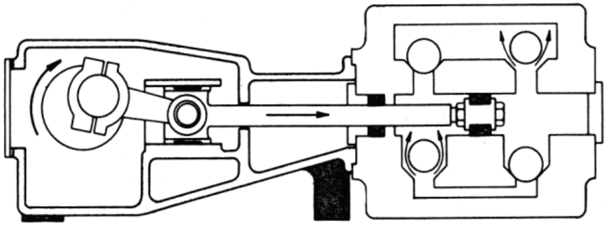
Engine End or Steam End



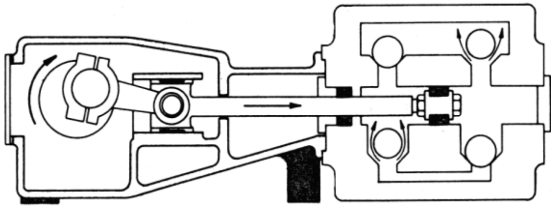
Pump End or Liquid End

Duplex Piston Pump

Power Pumps

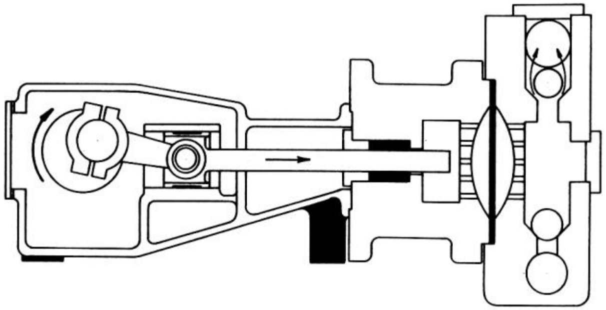


Plunger Pump



Piston Pump

2. Diaphragm



Reciprocating Power Mechanism Diaphragm Pump

Pressure Pulsations of Positive Displacement Pumps

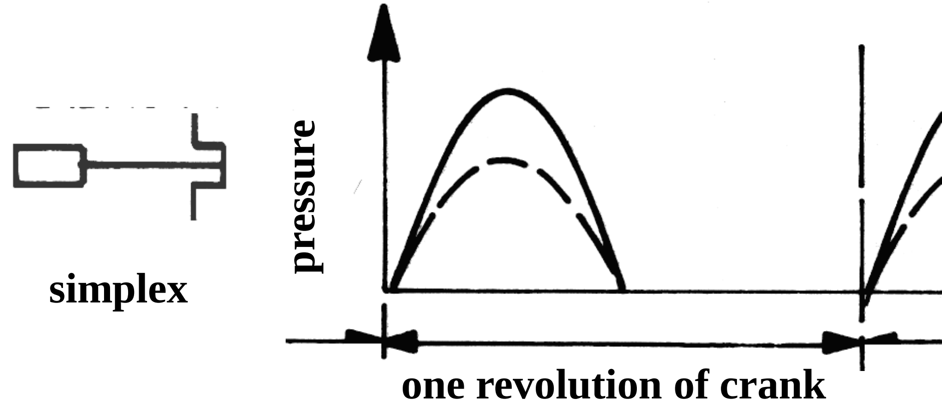
Positive Displacement pumps, especially the reciprocating type have a pulsating pressure pattern at suction and especially at discharge.

Reduction of pulsations is achieved by increasing the number of discharges per revolution.

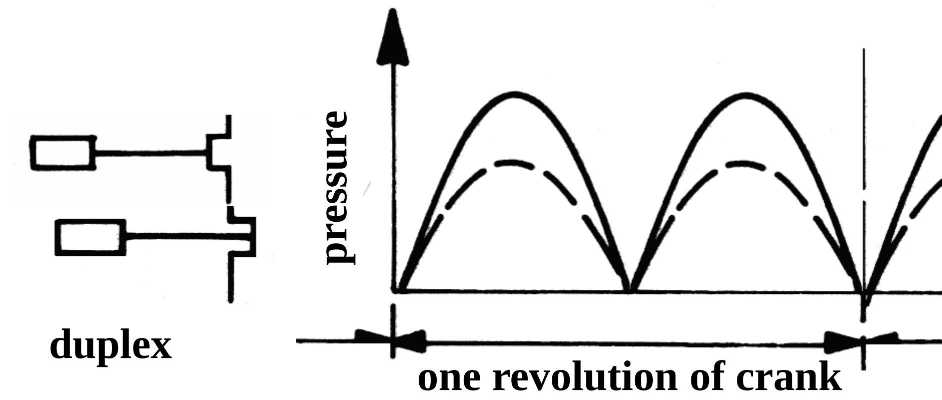
Thus a duplex pump has a smoother flow pattern and a triplex smoother than a duplex.

Similarly gear pumps have a smoother flow pattern than lobe pumps and so on.

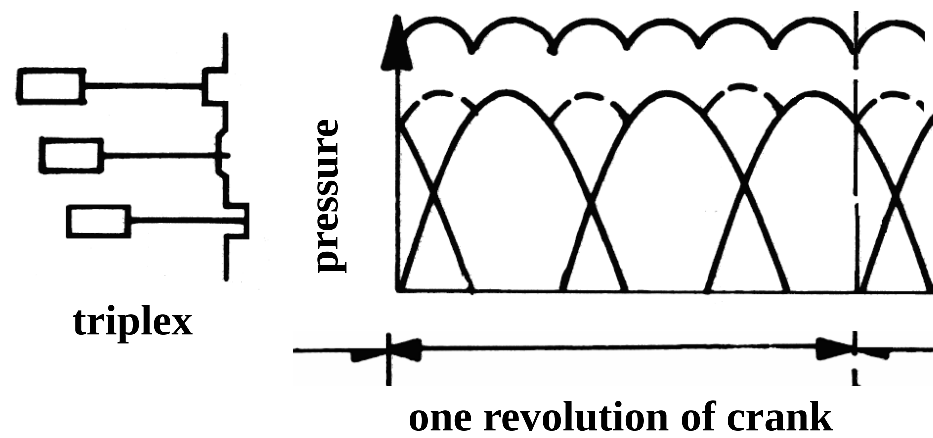
One crank one cylinder



Two cranks two cylinders 180° apart



Three cranks three cylinders 120° apart



Pulsation Dampeners (i)

Dampeners are used to reduce discharge and suction pulsations. Pulsations are more pronounced when the:-

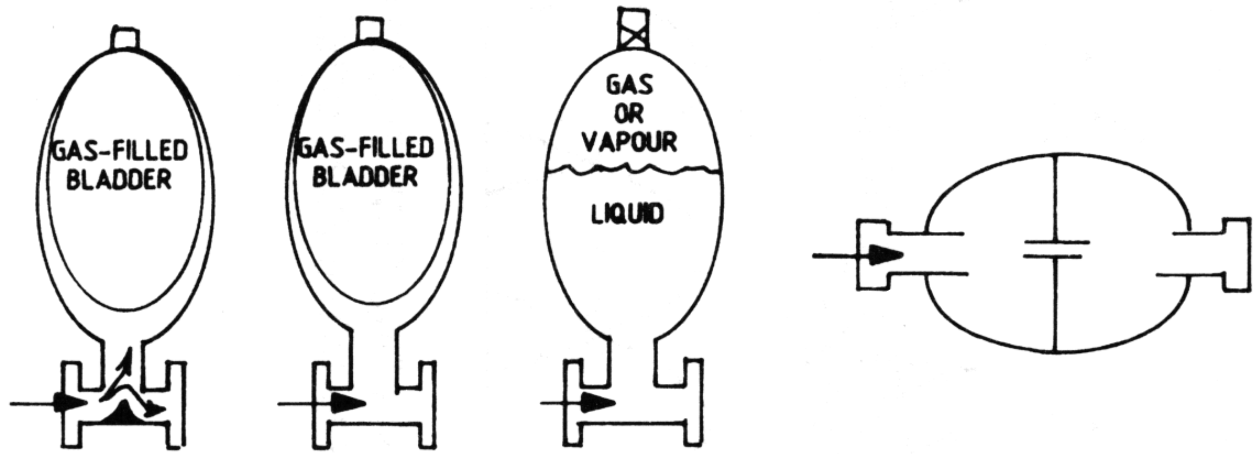
- piping associated with the pump is long,
- pressure high,
- discharge volume comparatively high and pulsating
- high liquid density and viscosity, high liquid acceleration and inertia.

A properly chosen, sized and located dampener can reduce the system pulsations considerably. The dampeners are most effective when located as close to the pump suction and discharge as possible. Sizing requires careful consideration of a number of variables as referred to above.

A practical size indication is 12x the pump displaced volume and the charge pressure of the bladder or gas filled type is 66% of the system pipe pressure.

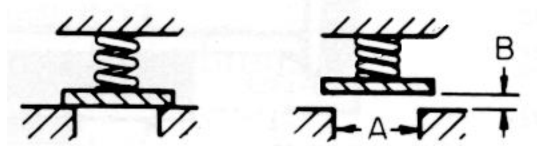
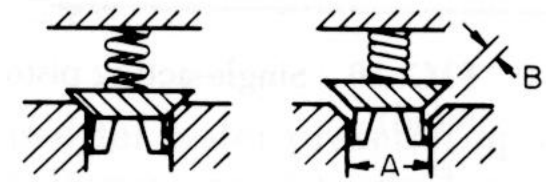
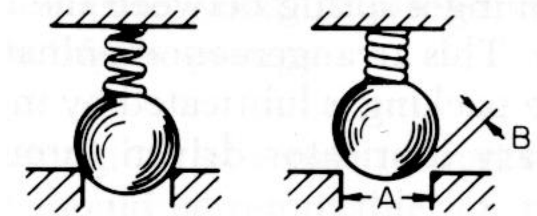
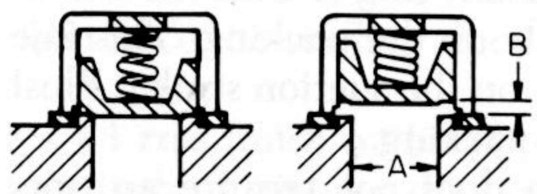
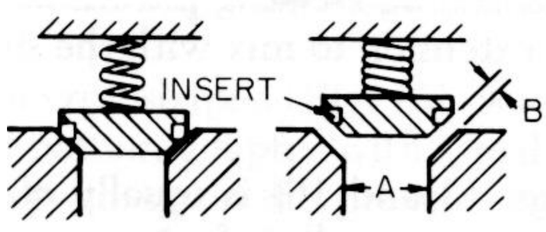
Furthermore a dampener can be installed on the suction side to act as an accumulator to give the pump a ready supply of liquid on each suction stroke thus influencing NPSH(A) conditions.

Pulsation Dampeners (ii)



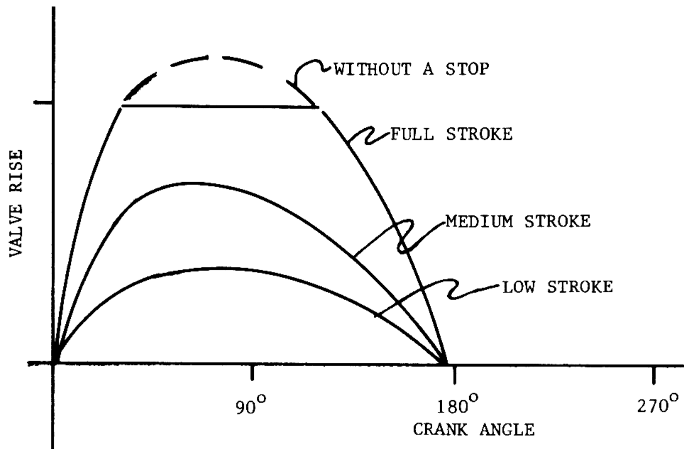
	Diverter	Appendage	Gas Over Liquid	Acoustic
Attenuation				
Low Frequency	Good	Good	Good	Poor
High Frequency	Fair	Poor	Poor	Good
Pressure Loss	Low	Negligible	Negligible	High
Effectiveness				
Variable Speed	Good	Good	Good	Poor
Solids Content				
of Pumped Liquid	Poor	Very Good	Good	Poor

Reciprocating Pump Valves

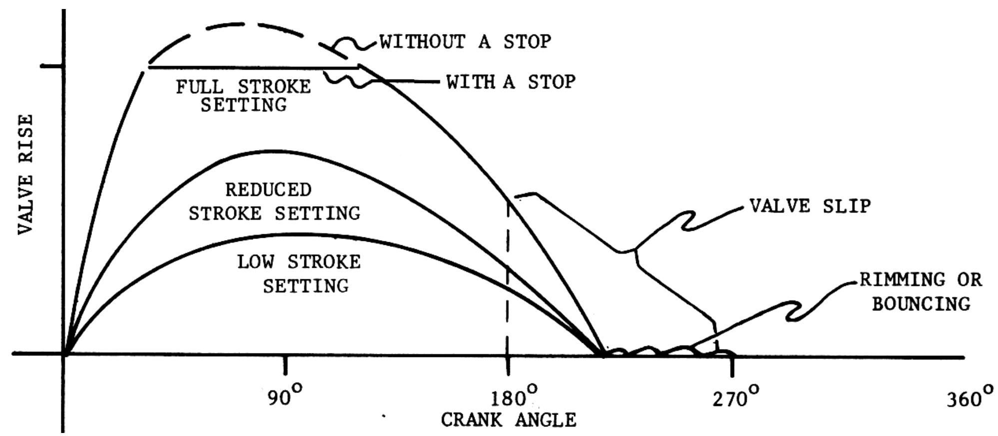
Type	Diagram	Max. Press. (bar)	Application
Disc		350	Clean Liquid
Wing		700	Clean Chemical
Ball		2000	Liquid with particles Clean Liquid at High Pressure
Plug		400	Chemicals
Cone		170	Slurries. Valves have elastomeric insert

Valve Slippage (i)

Valve slippage is the amount that either leaks through a pump valve when it is closed or flows through the valve when it should be closed and has actually failed to close. Valve Slippage results in loss of rate of flow.



Valve Action without Slippage



Valve Action with Slippage

Slippage is influenced by:-

Pressure. **The higher the pressure the higher the slippage**

Speed. **The slower the pump speed the higher the slippage**

Viscosity. **The higher the viscosity the higher the slippage**

Machining Tolerances. **Poor machining tolerances or loose valve guiding permit higher leakage. If the valve seats off centre, the contact on closing creates a circling effect allowing slippage. This circling effect is called rimming.**

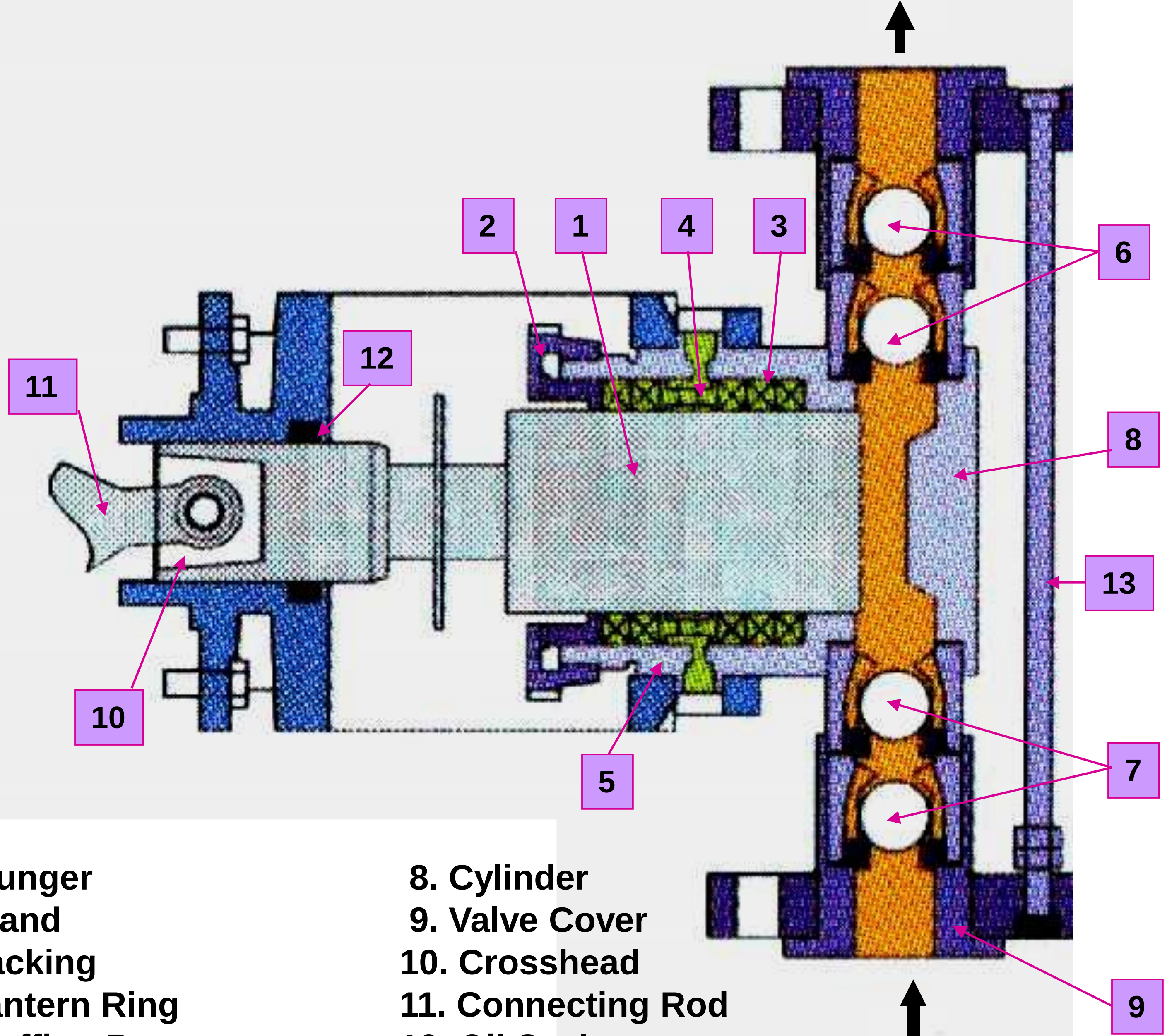
Valve Loading - **ie. Spring loading or weight of valve element. Increased valve loading decreases valve slippage.**

Valve Slippage (ii)

Excessive valve slippage can be improved by the following arrangements:-

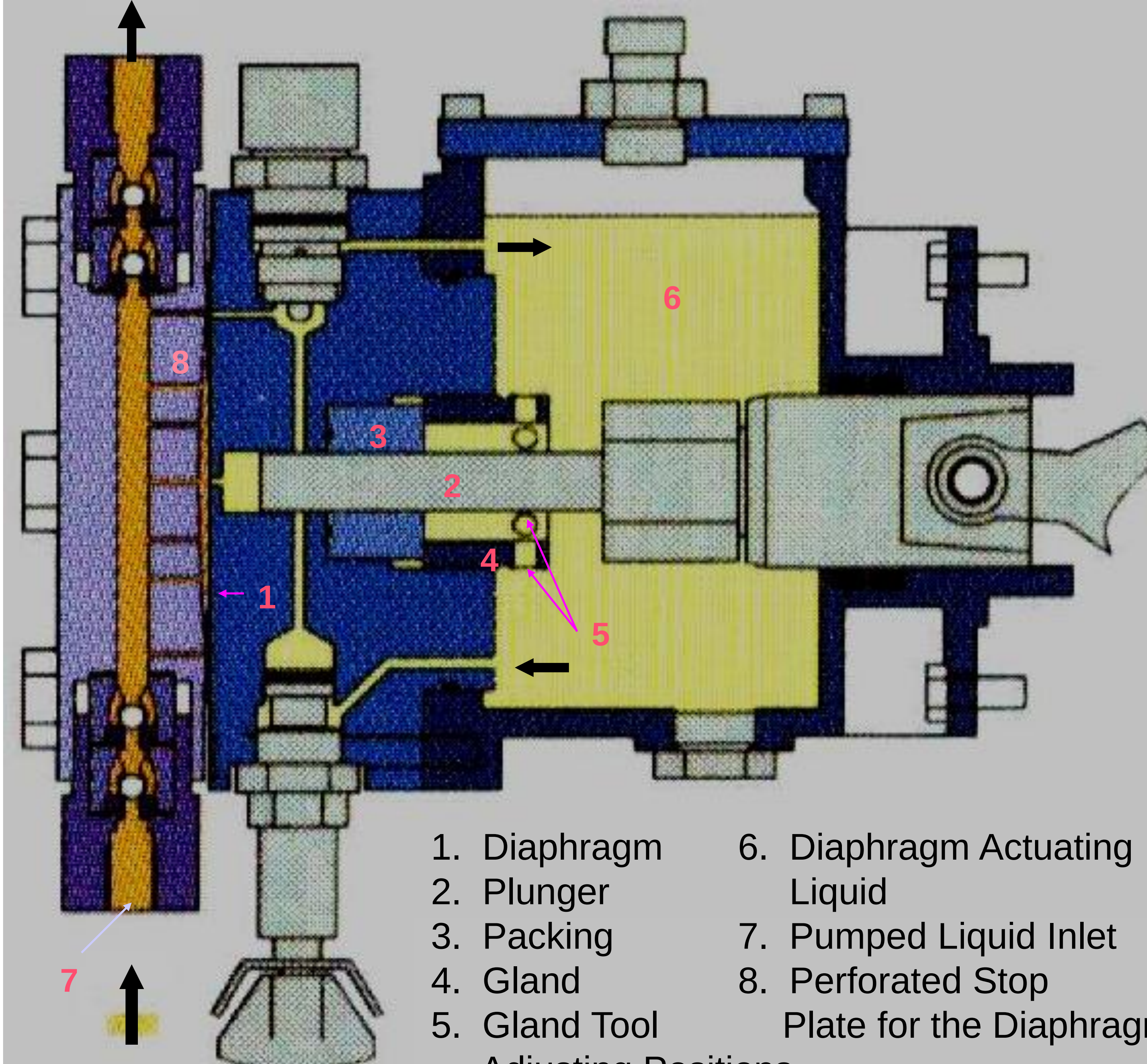
1. Use Double Check Valves
2. Use Spring Loaded Valves
3. Use Heavier Valve Moving Element
4. Use Valves with greater seat opening and lower valve lift
5. Use Valves with better guiding of the moving valve element
6. Use higher quality valves with closer machining tolerances
7. Use valves made of corrosion resisting materials unaffected by the pumped liquid.
8. The presence of solids or abrasives in the pumped liquid requires valves with soft elastomeric seats or hardened seats
9. Liquids producing a coating on the valve parts or viscous liquids require sharp seats to break up the coating effect. In this case the valve guiding must be loose to take account of the viscosity and coating effect but the valve must not be sloppy.
10. Use valves with large area of contact between the moving element and the valve stop. The stop section of the valve and the corresponding valve element surface are subjected to high stresses and wear especially when the area of contact is small.

Liquid End of a Standard Reciprocating Pump



1. Plunger
2. Gland
3. Packing
4. Lantern Ring
5. Stuffing Box
6. Double Discharge Valve
7. Double Suction Valve
8. Cylinder
9. Valve Cover
10. Crosshead
11. Connecting Rod
12. Oil Seal
13. Tie Rod

Liquid End of a Diaphragm Positive Displacement Pump



1. Diaphragm
2. Plunger
3. Packing
4. Gland
5. Gland Tool Adjusting Positions
6. Diaphragm Actuating Liquid
7. Pumped Liquid Inlet
8. Perforated Stop Plate for the Diaphragm

Positive Displacement Metering Pumps (1)

A metering pump is a special type of positive displacement pump, usually reciprocating, which is designed and used to transfer liquids at an accurately controlled rate. It is a controlled volume machine the pumping rate of which can be altered by a simple adjustment, effected externally, at predetermined intervals of time, of the displaced volume of the pump. The accuracy of the transferred volume of liquid is important and should be unaffected by system operating pressure variations. The accuracy of the true metering pump is limited only by the design and virtually not by external influences.

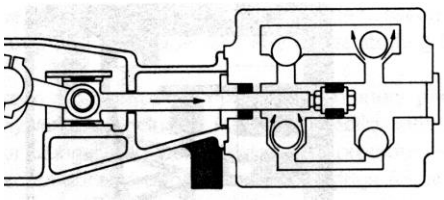
Other types of positive displacement pumps which have fixed capacities at a certain single driving speed can only change their rate of output by altering the driven speed. Inaccuracies in the controlled discharge volume in this case arise from the speed control system as well as the inaccuracies of the pump itself. In several instances accuracy is distorted also by system pressures.

Metering pump flow rates can be predetermined accurately with flows maintained consistently within ±1%

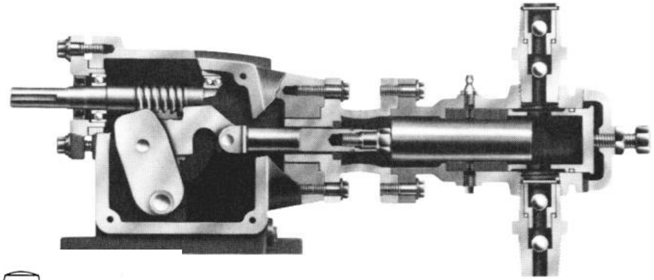
Positive Displacement Metering Pumps (2)

Types of Positive Displacement Metering Pumps:-

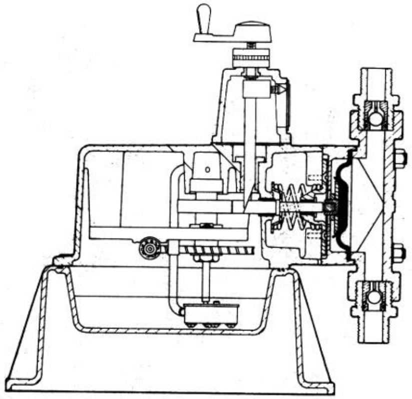
1. Piston



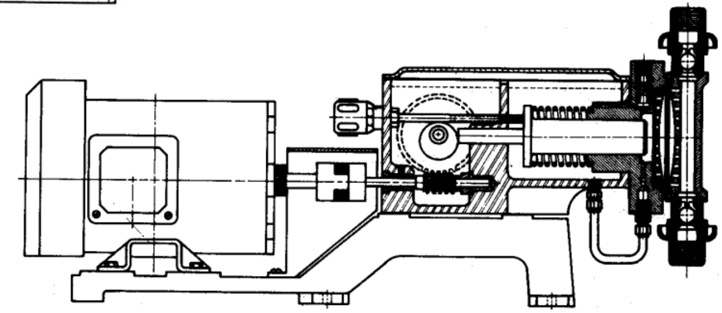
2. Packed Plunger



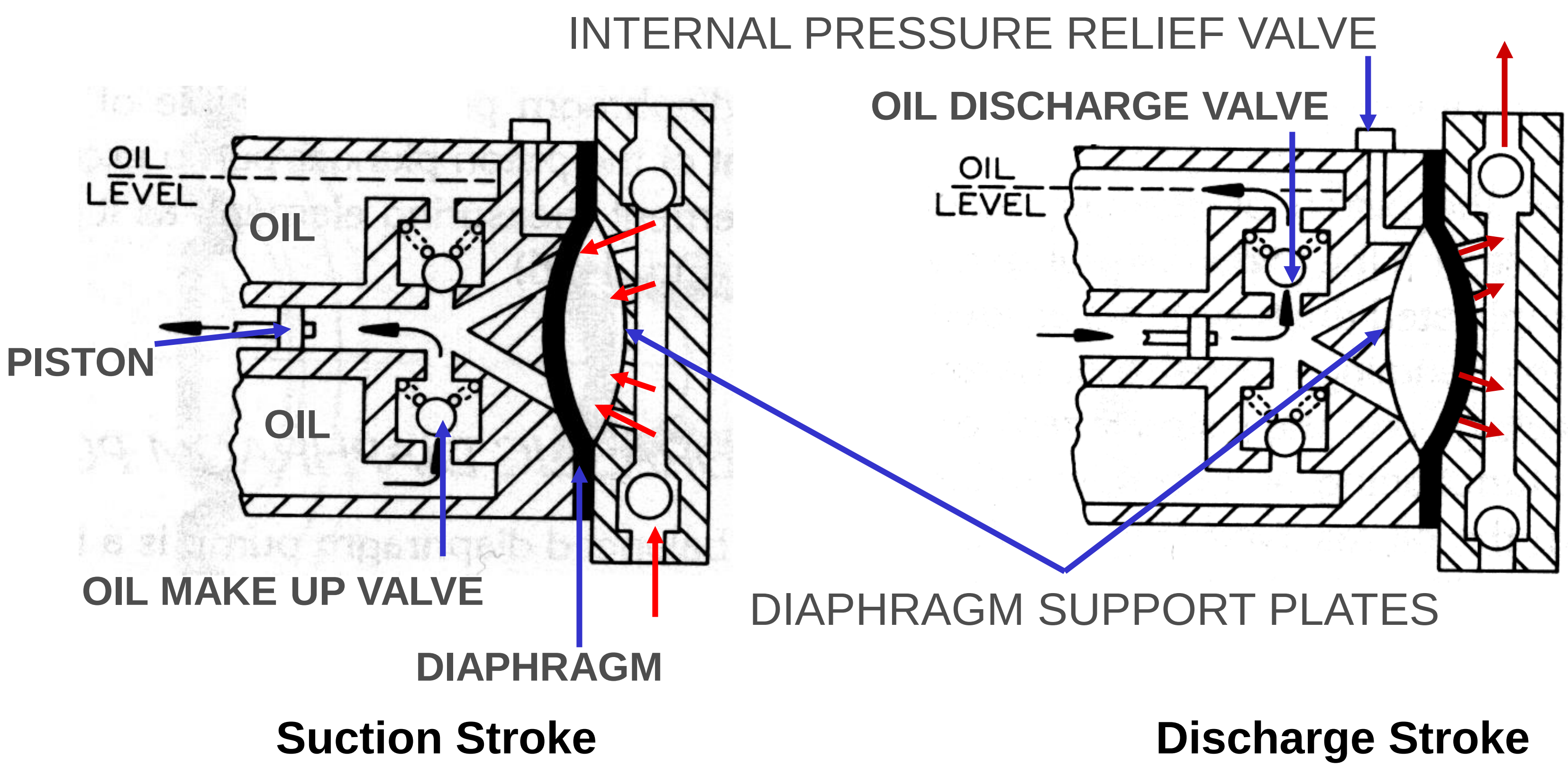
3. Mechanical Diaphragm



4. Hydraulic Diaphragm

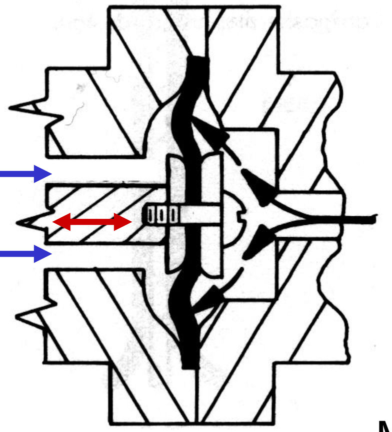


Hydraulic Diaphragm Pumps

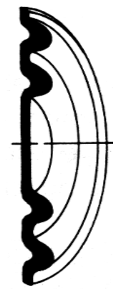


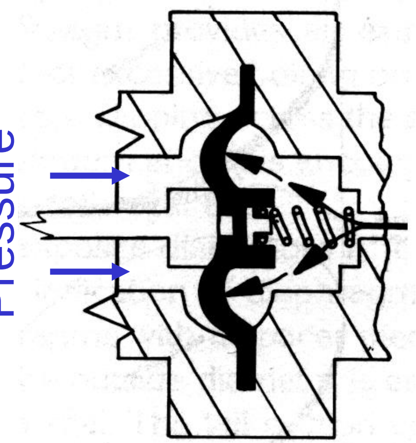
To overcome the leakage problem through the packed piston gland a diaphragm pump is used. Leakage has to be avoided when the pumped liquid is very costly and when it is highly corrosive, poisonous or polluting. When the liquid is highly poisonous a pump with two diaphragms is used so that when the main diaphragm fails the second one can prevent leakage until when the failed diaphragm is replaced. A sensor is used to detect leakage due to the failure of the main diaphragm.

Some Types of Reciprocating Pump Diaphragms



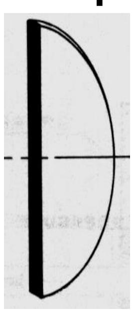
Convoluted Diaphragm

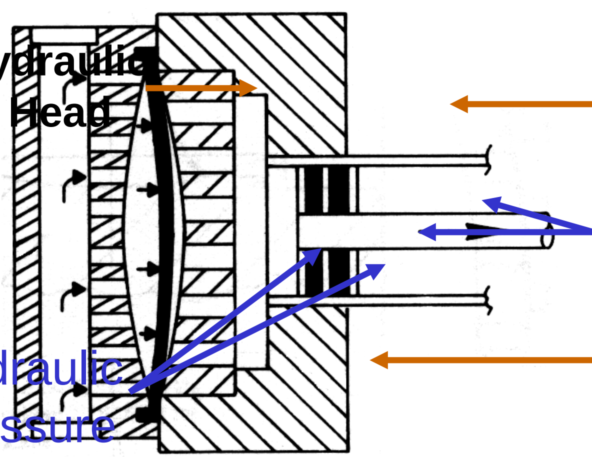




Mechanical Diaphragm Actuation

Flat Diaphragm





Hydraulic Diaphragm Actuation

Some Other Diaphragm Arrangements

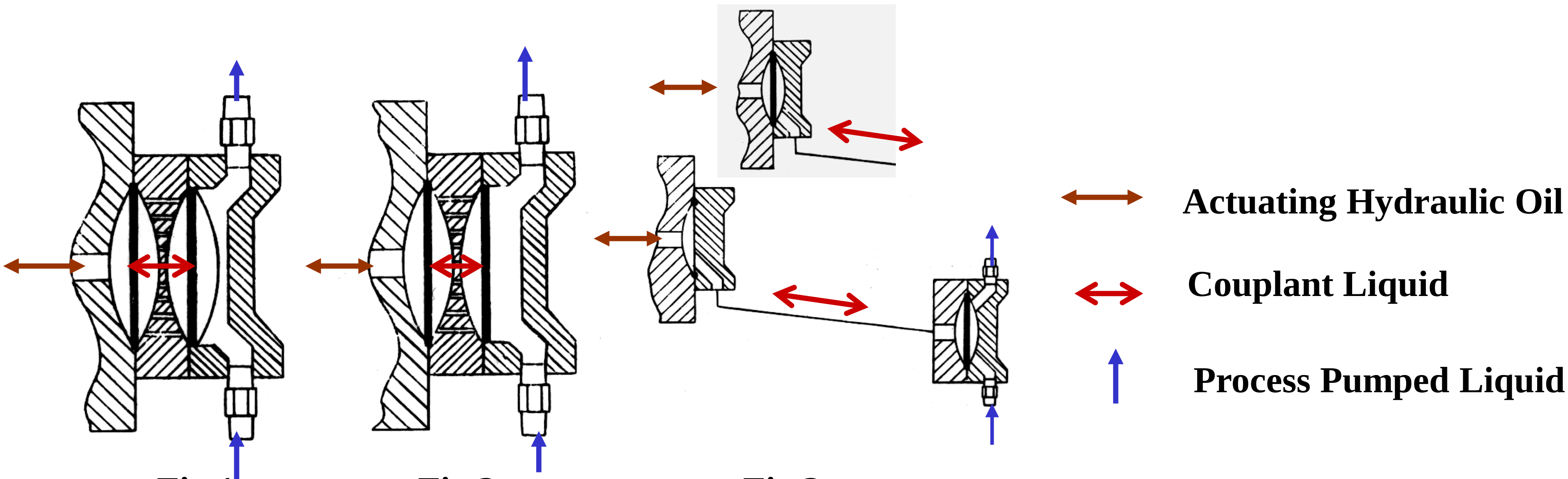


Fig 1 **Fig 2** **Fig 3**

Fig 1 A double diaphragm arrangement provides additional assurance of permanent separation of the hydraulic fluid and of the environment from the fluid being pumped, which is usually toxic, highly corrosive, polluting etc.

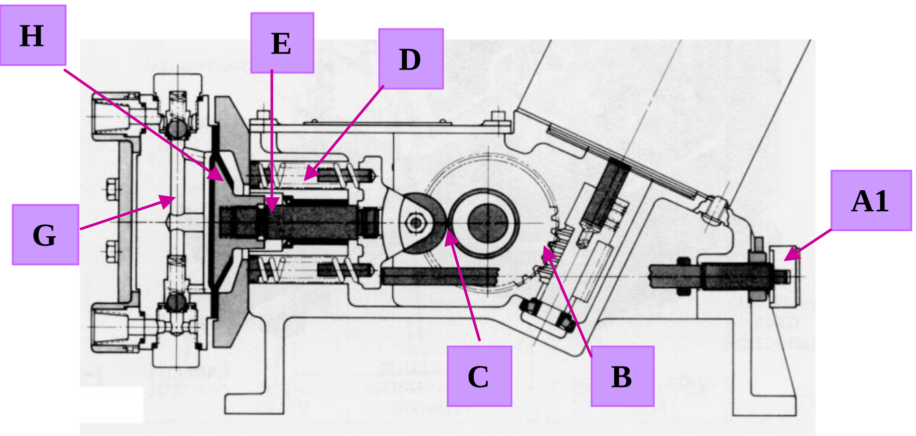
Fig 2 A double diaphragm without front backing plate provides a wide unobstructed flow passage for viscous liquids or slurries.

Fig 3 A remote pumping head with interconnecting hydraulic piping is provided when the process liquid is at high temperature or when for convenience or safety reasons (e.g. radioactive process liquid) the pumping head should be away from the pump

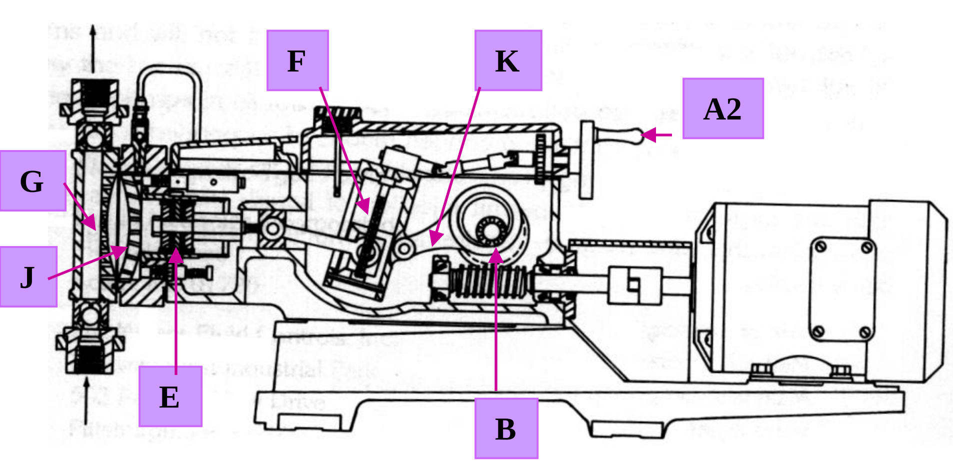
Adjustment Mechanisms for Controlling the Capacity of Metering Pumps (i)

Adjustment Mechanisms presently in use may be grouped as follows:-

1. Mechanical Lost Motion



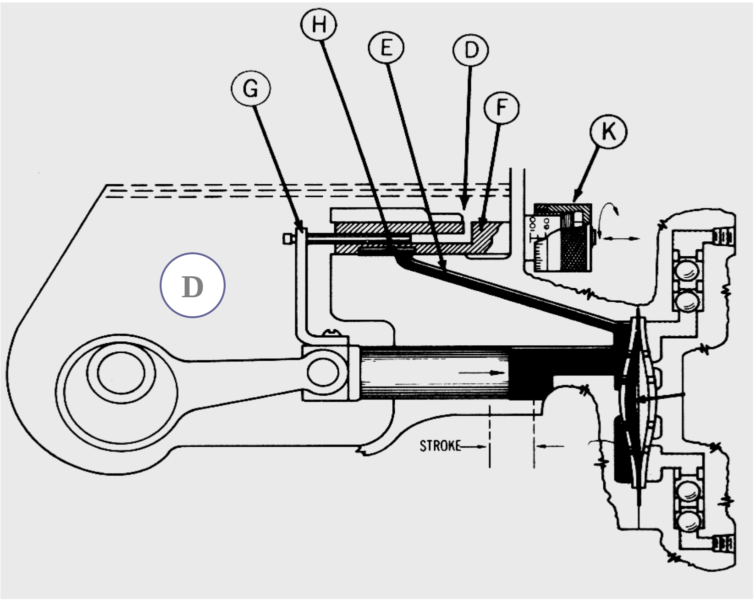
2. Adjustable Crank



A1. External Stroke Adjustment with Vernier
A2. External Stroke Adjustment Handwheel
B. Worm Gear Speed Reducer
C. Eccentric and Follower
D. Piston Return Springs
E. Piston
F. Stroke Adjustment Assembly
G. Pump Head Assembly
H. Mechanical Diaphragm
J. Hydraulic Diaphragm
K. Connecting Rod

Adjustment Mechanisms for Controlling the Capacity of Metering Pumps (ii)

3. Hydraulic by-pass



The hydraulic oil is pumped from the oil reservoir by a constant stroke plunger to the diaphragm chamber and then through passage E. External adjuster K controls the position of control valve F which with the piston follower G control the amount of oil bypassing through by-pass shut off H. For maximum flow rate H is shut off and for no flow H is totally open, by-passing the entire quantity of oil pumped to the reservoir D.

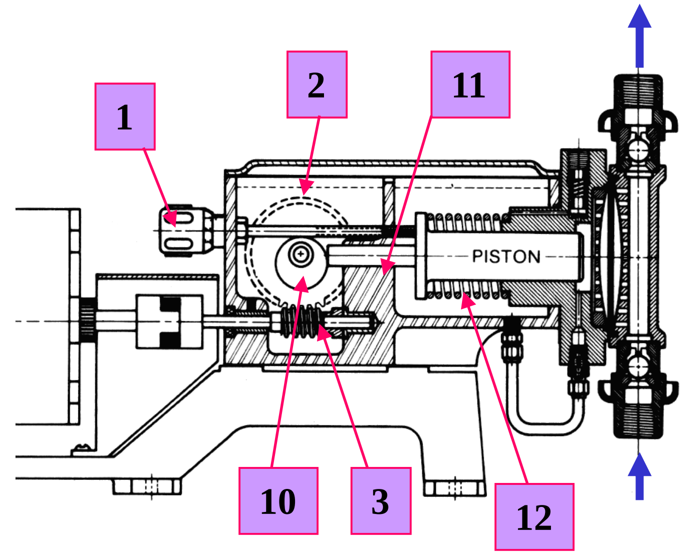
4. Electromagnetic Lost Motion

The plunger is energized electromagnetically by encapsulated electronics to provide reliable long life and high performance. The stroke length and speed adjustment can be either manual or it can be connected to an electronic digital or analogue system. These units are compact and have a wide range of small outputs.

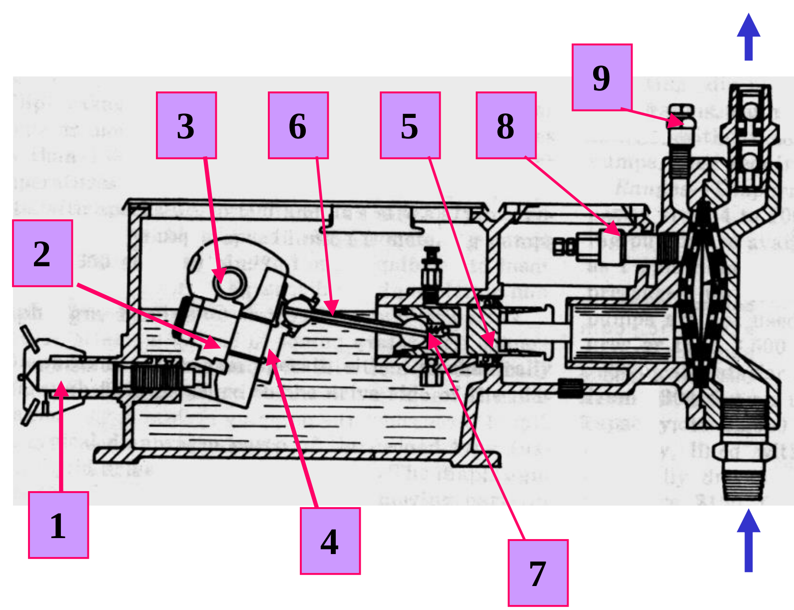
Some Other Stroke Adjustment Mechanisms

1. Manual Stroke Adjuster
2. Worm Wheel
3. Worm
4. Rotating Crank
5. Crosshead
6. Connecting Rod
7. Lubricating Oil Pump
8. Integral Relief Valve
9. Air Bleed
10. Rotating Eccentric
11. Piston Rod
12. Return Spring

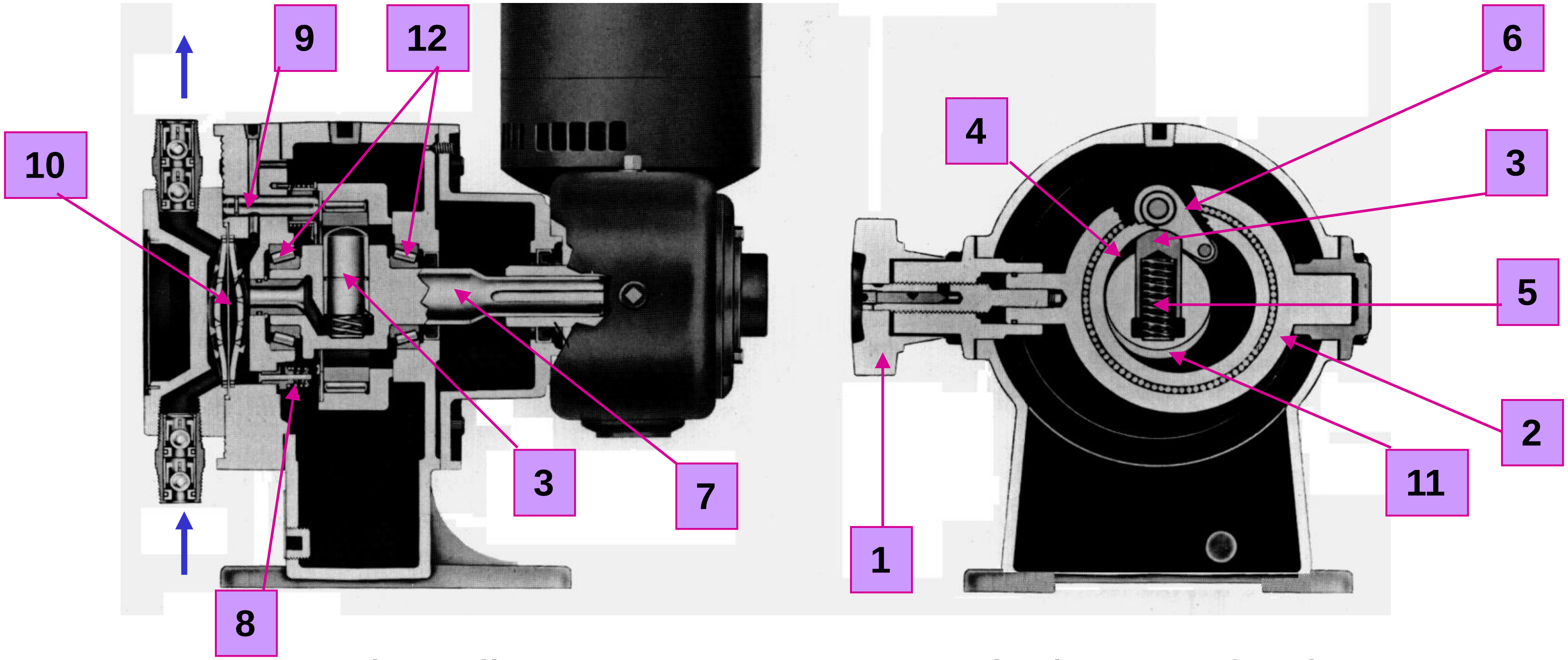
Mechanical Lost Motion Type



Adjustable Crank Type



Rotary Plunger Metering Pump



1. Stroke Adjuster
2. Shift Ring altering the length of stroke
3. Plunger, the only reciprocating part.
4. Reaction Ring on which the plunger slides
5. Return Spring
6. Indexing arm for the the air venting mechanism
7. Drive Shaft
8. Preset Refill Valve admitting make up oil to the plunger
9. Air Venting mechanism
10. Balanced Diaphragm
11. Cam for operating the air vent
12. Taper Roller Bearings for the shaft

Specifying Metering Pumps

In specifying a metering pump at first the capacity in terms of flow rate and discharge pressure should be identified.

It is important not to oversize or undersize a metering pump. It should be sized so that the maximum expected flow rate is 80% to 85% of the pump capacity. This leaves additional capacity if needed. The minimum capacity should never be less than 10% of the pump capacity. Ideally, the metering pump will operate at all times between 10% and 100% of capacity. Different speeds can be used as well.

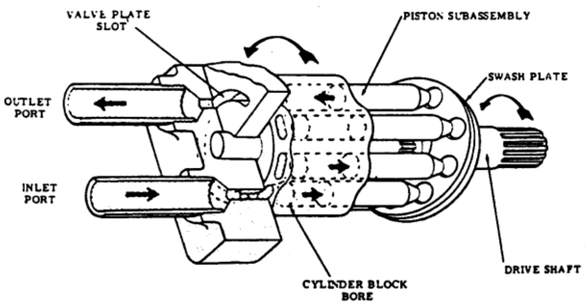
Stroking speeds can range from 18 to 144 spm, (strokes per minute). Stroking speeds on diaphragm pumps are not as critical as they are for packed plunger pumps where higher speed would cause wear and high leakage loss. The moving parts in hydraulically balanced diaphragm pumps offer a long and reliable service even at high stroking speeds. High stroking speeds should be avoided with abrasive chemicals. Also, low stroking speeds should be avoided if variable speed drives are to be used since the pump should never be operated at less than 15 spm, as accuracy below this value cannot be secured. If metering pumps are chosen well accuracies in the region of ±0.5% are common.

Miscellaneous Positive Displacement Pumps

In the same way miscellaneous positive displacement pumps may be grouped as follows:-

1. Sliding Vane
2. Rotating Piston
3. External Vane
4. Flexible Member

1



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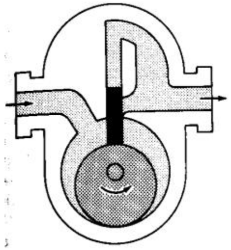

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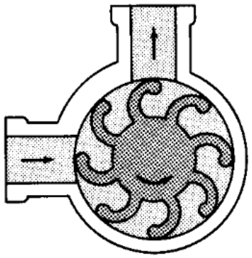
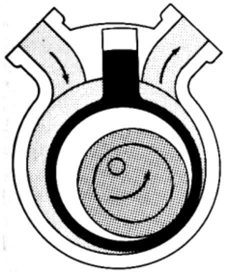
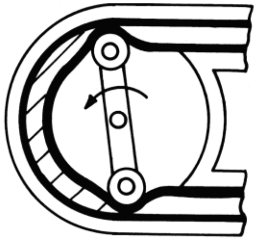


Flexible Impeller



Flexible Liner



Flexible Tube

Positive Displacement Pump Principles

Pump Swept Volume (Q_O) is the total net pump fluid space displaced during one complete revolution of the driving rotor.

Pump Displacement (Q_D) is the total net pump fluid space displaced in a given unit period of time.

In practice there is always leakage from the high to the low pressure pump spaces through the necessary clearances between the moving and the stationary components. This is termed the leakage flow (Q_L). Thus the

Actual Flow Rate $(Q_A) = (Q_D) - (Q_L)$

The Volumetric Efficiency $\boldsymbol{\eta}_V = (Q_A) / (Q_D) = 1 - (Q_L) / (Q_D)$

The energy delivered to the pumped liquid (Liquid Power)* $(P_L) = (Q_A) \times H$ where H is the total head increase of the pumped liquid

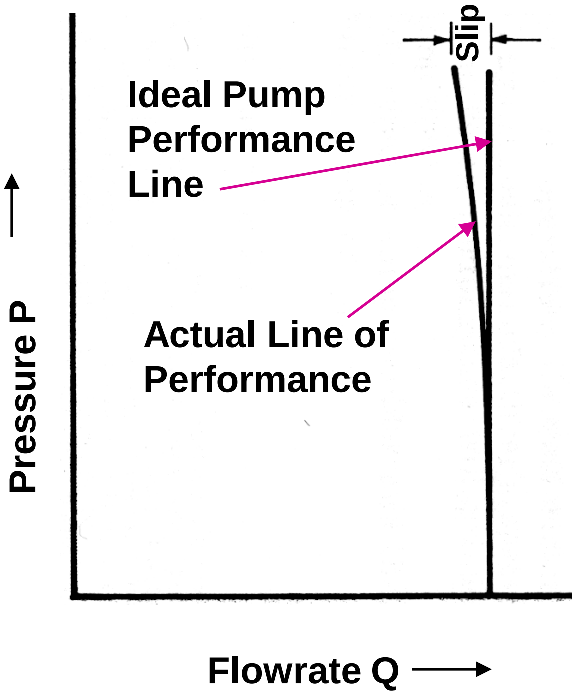
The Pump Efficiency $\boldsymbol{\eta}_P = (P_L) / (P_I)$ where (P_I) is the power input into the pump at the pump shaft i.e. (P_I) = motor power input x motor efficiency.

* Liquid Power can also be expressed as hp=(gpm x psi)/1714 or kW=(m^3/hr x bar)/36

Positive Displacement Pump Performance 1

Positive displacement pumps will develop the same pressure on any liquid that can flow into the pump chamber.

They are essentially constant volume machines in that the flow rate can only be changed by varying
1) the rotational speed
2) the swept volume.
In practice pressure influences capacity because of leakage through the seals, the higher the pressure the higher the leakage. The difference between the ideal and the actual flowrate is called "slip"

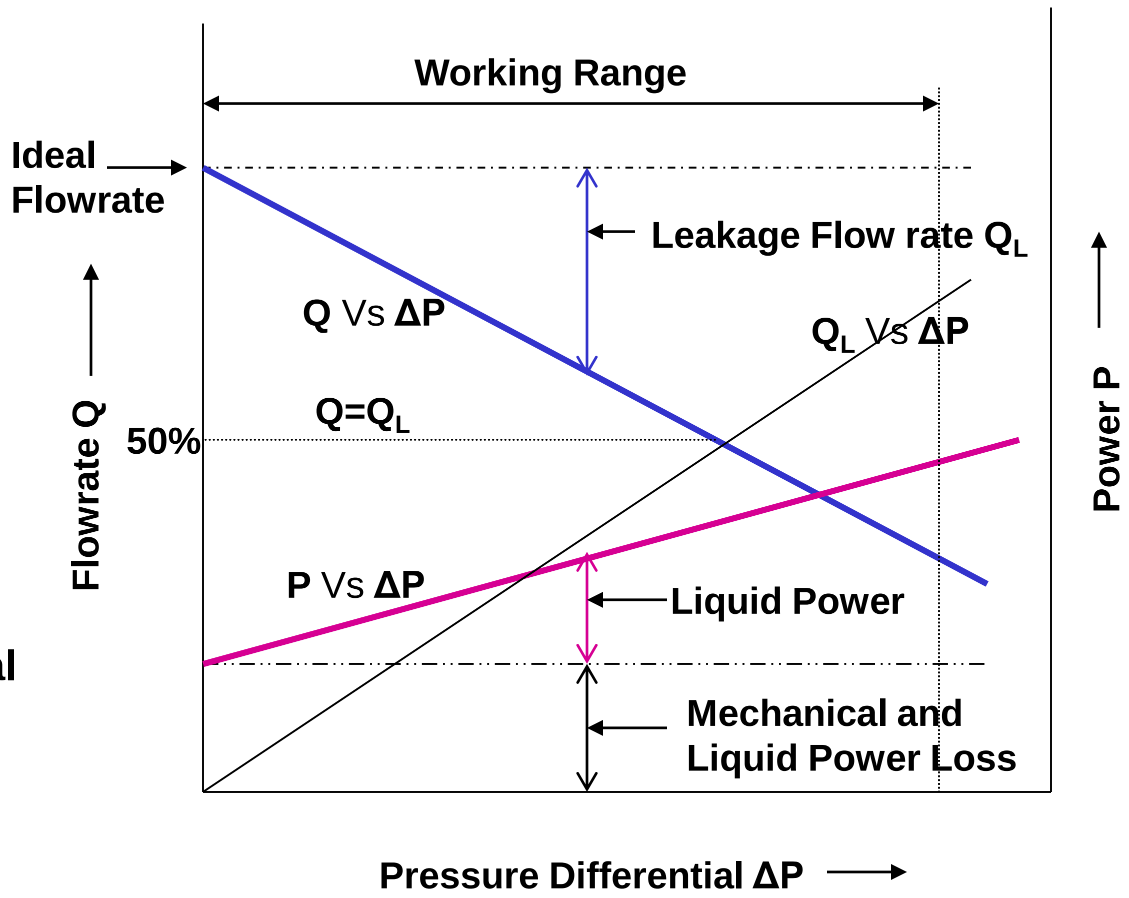


The volumetric efficiency compares the actual flowrate to the ideal i.e. Volumetric efficiency = Actual Flowrate/Ideal
or Volumetric Efficiency = (Ideal Flowrate - Slip)/Ideal

Positive Displacement Pump Performance 2

The Effect of Pressure Rise

It is assumed that the Pump Speed and Liquid Viscosity are Constant and that the Pump Pressure Differential Varies



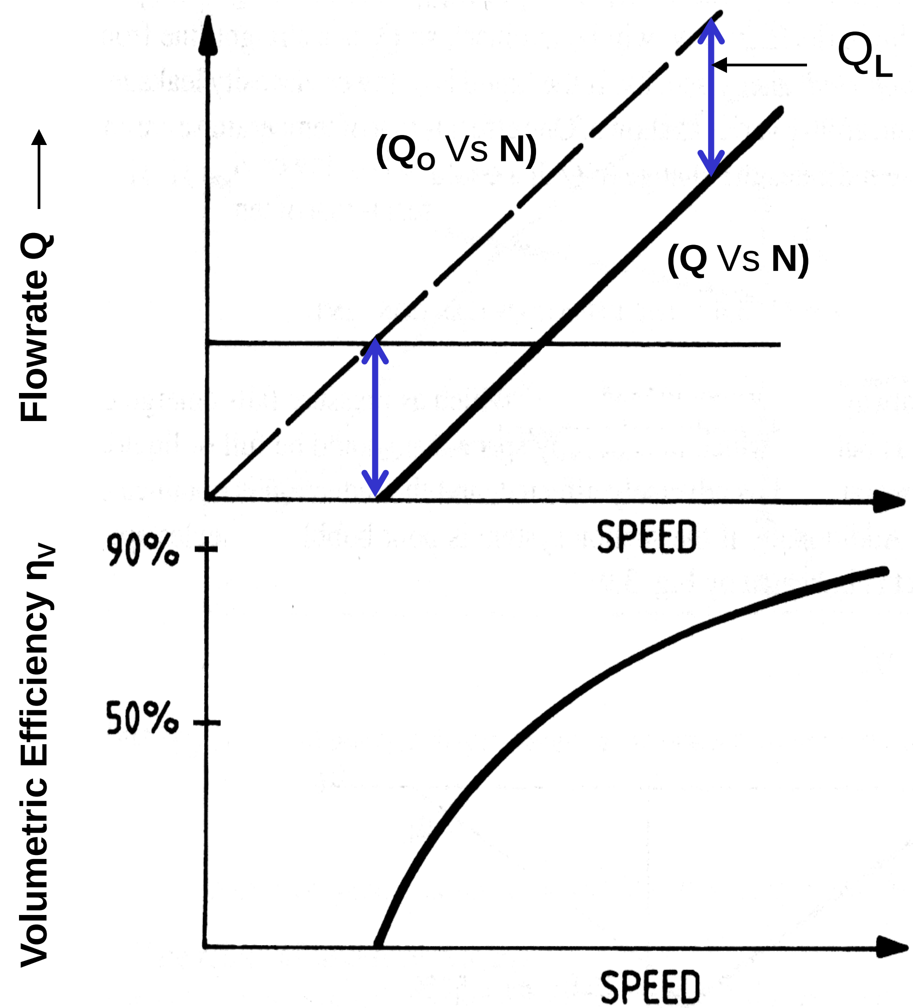
When the leakage quantity (Q_L) is equal to the liquid flowrate (Q) the working range of the pump is practically limited. At this point the volumetric efficiency is 50% and over this the leakage rate is higher than the delivery.

Positive Displacement Pump Performance 3

The Effect of Pump Speed Change

It is assumed that the Liquid Pressure Rise and the Viscosity remain constant and that the pump speed changes.

The ideal flowrate Q_o increases with pump speed and the leakage flowrate Q_L is practically constant. Therefore the actual flowrate Q is displaced by Q_L below the ideal line. The relationship holds substantially true until at high speeds the liquid may not completely fill the pumping volume.



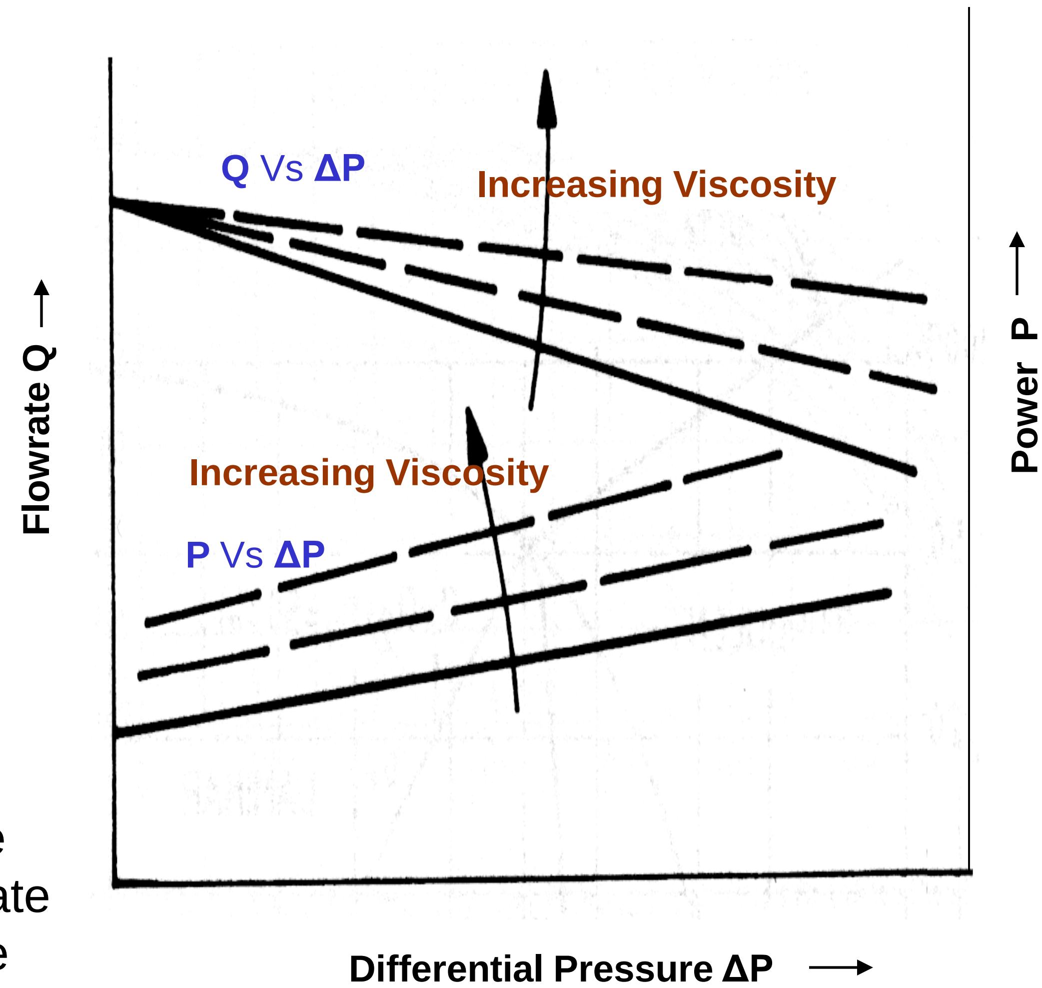
As the leakage quantity remains substantially constant it follows that as the flowrate Q increases with speed the volumetric efficiency increases also tending to a constant value at high speeds as $\eta_V = (Q_o - Q_L)/ Q_o = 1- (Q_L/ Q_o) = 1\text{-}K/N$ where K is a constant and N is the speed

Positive Displacement Pump Performance 4

The Effect of Viscosity

It is assumed that the pump speed is constant.

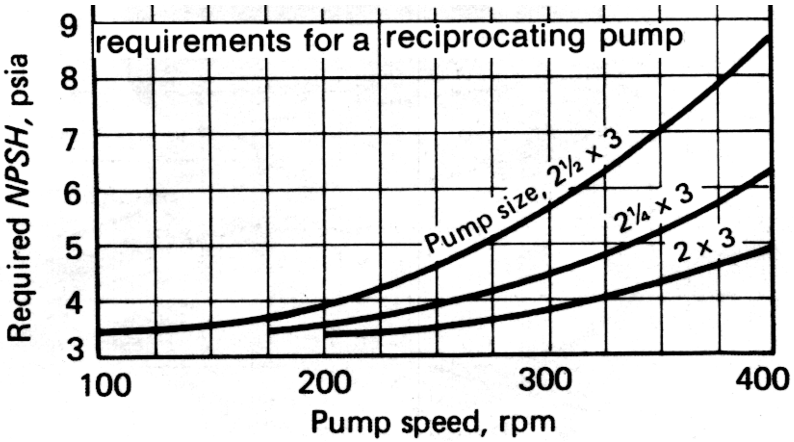
Increasing viscosity requires a higher power input for the same flowrate as it is more difficult to force the viscous liquid through the pump. Similarly it is more difficult for the liquid to be discharged through the leakage paths to lower pressure areas and so leakage flowrate is reduced with increasing viscosity thus the flowrate delivered is higher. The higher flowrate through the total differential pressure and in most cases through a more difficult path requires and even higher power input.



Positive Displacement Pump Performance 5

Positive Displacement pumps also require a Net Positive Suction Head for the liquid to flow into the pump. However in the event that the available NPSH is insufficient the pump swept volume will not be fully charged as the liquid vaporizes as it enters the pump. This causes reduction in the outlet liquid volume, vibration, hammering and noisy operation, shocks and eventually mechanical failure especially in reciprocating pumps.

The NPSH required by a given size pump increases with pump speed.



Viscosity increases resistance to flow so increasing viscosity requires a higher NPSH especially in reciprocating pumps with the increased resistance to flow in the valves. However viscosity reduces the slip volume in pumps such as gear or screw where there is more net forward flow due to the reduced slip. Sufficient driving power and NPSH must be available to cope with the higher viscosity.

Flow Associated with Reciprocating Pumps

Due to the reciprocating action the piston for each stroke starts from the rest position at the dead centre; at this moment it has the maximum acceleration. The speed increases - almost sinusoidally in most cases, depending on the driving linkage - to the maximum speed at mid stroke when the acceleration is zero and then it decreases as the piston approaches the other dead centre, where it momentarily is at standstill and the deceleration is maximum. This pattern of motion is followed by the pumped liquid. The instantaneous pressure difference required to accelerate the mass of liquid in the pipe associated with the pump is called the acceleration head pressure.

The instantaneous pressure developed is equal to:-
the discharge vessel pressure plus the static head pressure plus the combined acceleration head pressure and associated pipe system frictional head pressure. When the acceleration head is maximum the frictional head is zero since the instantaneous velocity is zero. Flow velocities are low and so frictional losses at other points can be neglected in the case of simplex and duplex pumps.

Acceleration head pressures can be reduced by slowing the pump speed, increasing the associated pipe diameter and by introducing pulsation dampener