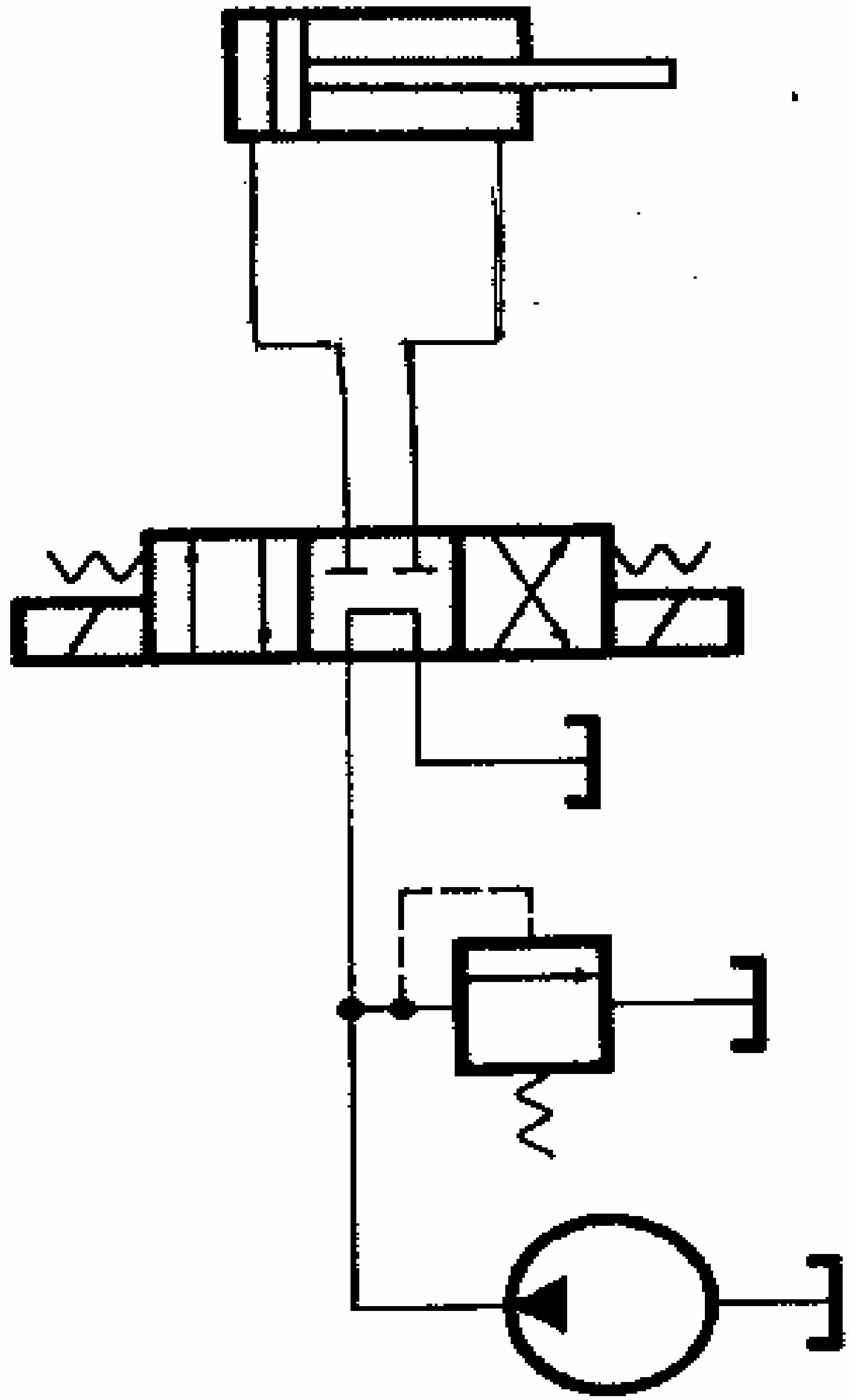
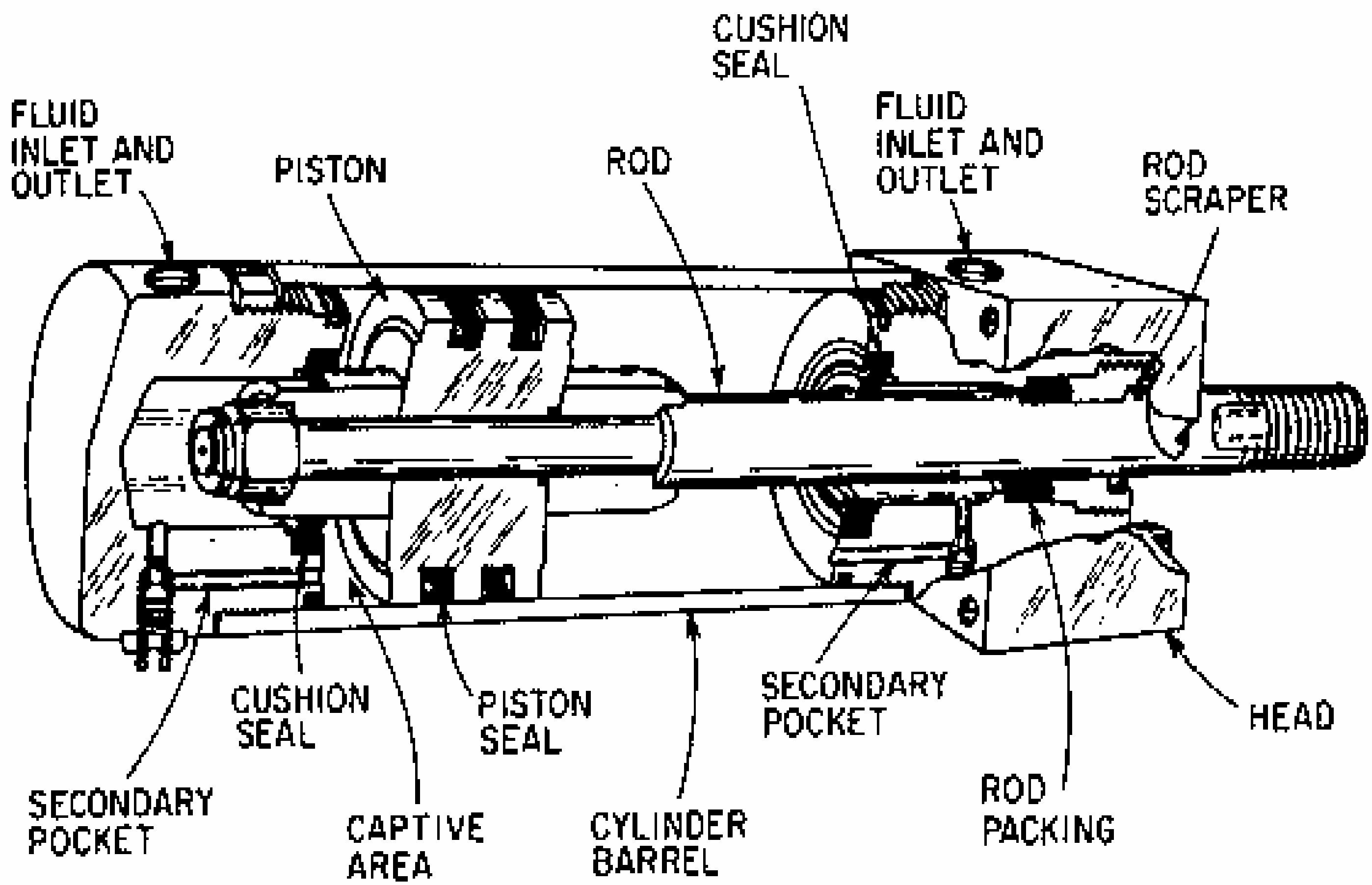
HYDRAULIC AND PNEUMATIC SYSTEMS

A simple hydraulic system is shown on the next page. A pump is used to supply high pressure hydraulic oil to a flow control valve which in turn sends the oil either to an actuator or to a sump. The circle represents the pump. A pneumatic supply looks similar except the arrow inside the circle is not shaded. In this case the circle represents a compressor or an air storage tank. The large rectangle made of squares represents the control valve: the cylinder with piston represents the actuator: the square is a pressure relief valve. The slash in the small rectangle at each end of the valve indicates that it is solenoid operated. The zig-zag line immediately next to each small rectangle means that springs are used to return the valve to its neutral position when both solenoids are deactivated. In this case, the oil from the pump goes directly back to the sump. When the bottom solenoid is deactivated and the top one is activated, the two arrows in the top block move down into the center block and create flow paths from the pump to the top of the actuator and from the bottom of the actuator to the sump. The flow of oil moves the piston rod assembly downwards. When the top solenoid is deactivated and the bottom one is activated, the flow of oil moves the piston rod assembly upwards.

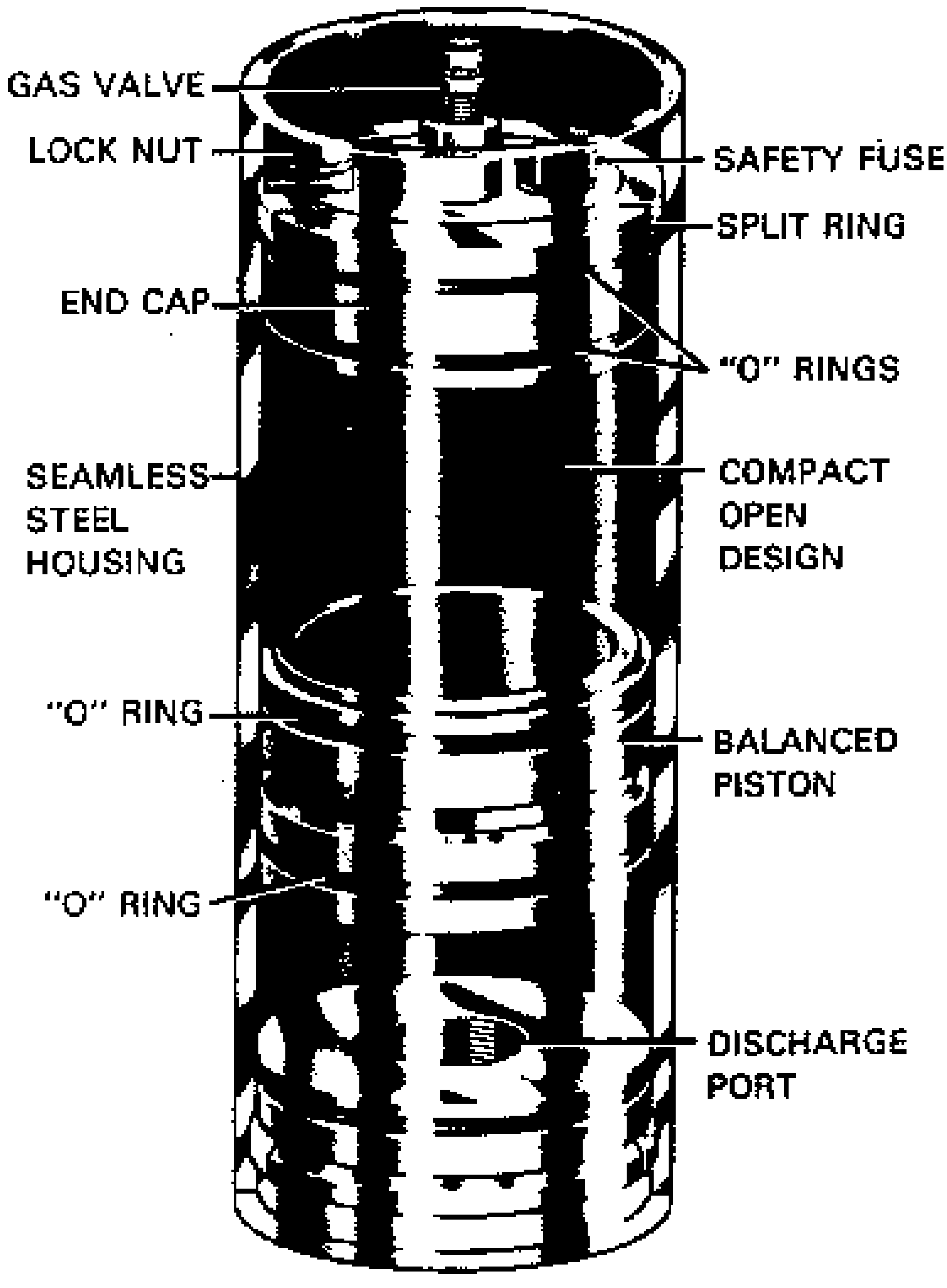


A schematic of a typical hydraulic actuator is shown on the next page. Pneumatic actuators look roughly the same. As can be seen, the actuator consists of a piston in a cylinder: a rod attached to one side of the piston passes through one end of the cylinder. When a rod is pushing against a stationary load, the pressure across the piston is around 20 MPa or 3000 psi. Special seals are needed to keep leakage of oil along the sides of the piston and the rod tolerable. The main ones are cup gaskets and piston and wiper rings. High pressure can cause regular o-rings to jam into the space between the piston and the cylinder walls. Pistons generally move very fast and they can slam into the ends of a cylinder. Special devices are needed to lessen impact loads. When they are constructed from flexible materials, they are known as cushions. The actuator shown in the schematic has a plug attached to each side the piston: as the piston nears an end a plug blocks oil passageways and this causes pressure to increase which in turn provides a cushioning effect. The plugs are shown in the actuator schematic.


FLUID
INLET AND
OUTLET
PISTON
ROD
CUSHION
SEAL
FLUID
INLET AND
OUTLET
ROD
SCRAPER
SECONDARY
POCKET
CUSHION
SEAL
CAPTIVE
AREA
PISTON
SEAL
CYLINDER
BARREL
SECONDARY
POCKET
ROD
PACKING
HEAD

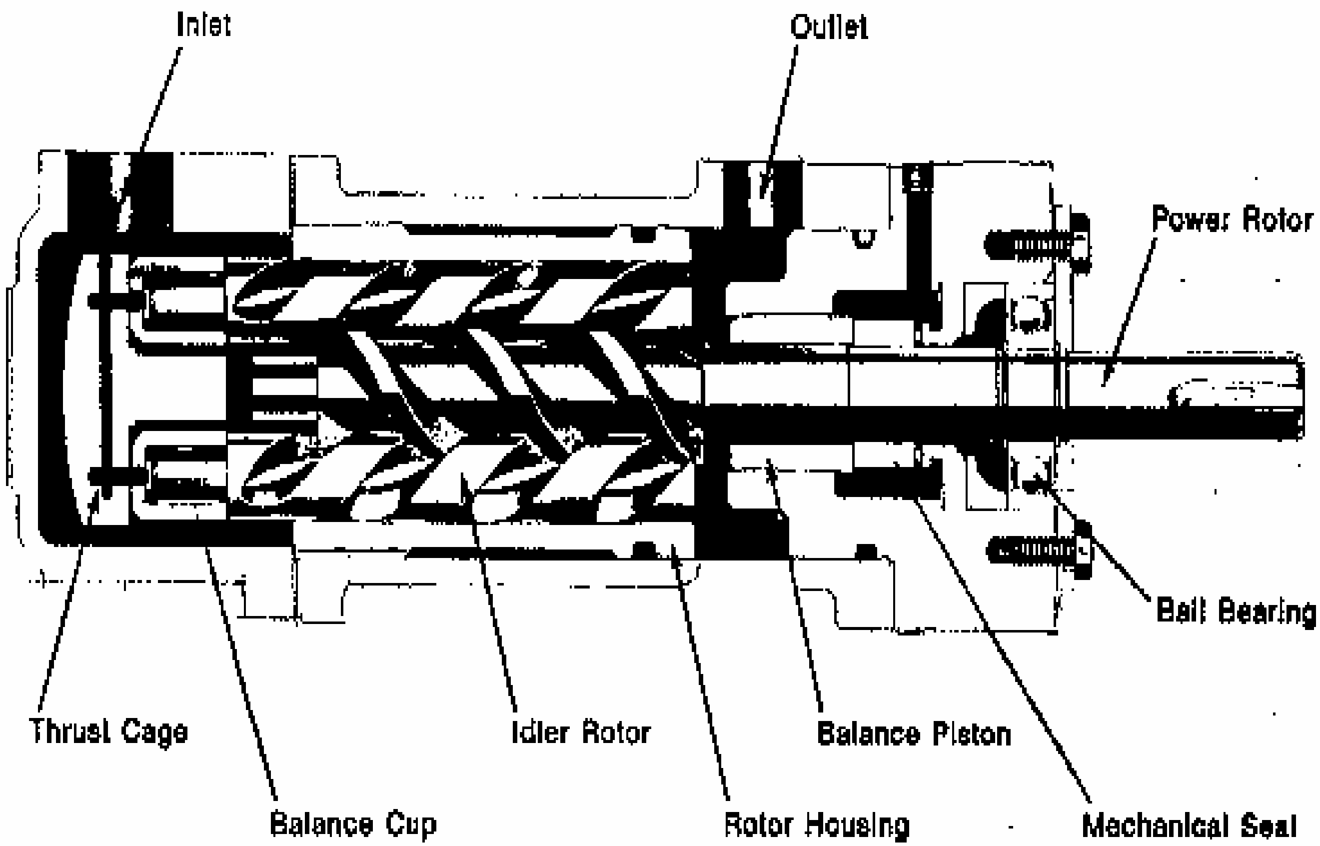
Conservation of mass considerations allow us to calculate the speed of an actuator rod. This gives Q=S*A where Q is the volumetric flow rate, S is the speed of the rod and A is the cross sectional area of the piston. Manipulation gives: S=Q/A. A simple static force balance gives the stalled load of an actuator. One gets F=P*A where F is the load and P is the pressure acting on the piston.

Hydraulic oil is basically incompressible. When load suddenly stops an actuator or there is a sudden valve closure, very high pressures can be generated in oil lines. Accumulators are used to counteract this. The sketch on the next page shows a typical accumulator. It consists of a tube with a piston. The part of the tube below the piston is open to the oil line: the part above contains nitrogen gas. During normal operating conditions, the gas pressure is approximately the same as that in the oil line. When pressure in the line suddenly goes up, flow of oil into the tube pushes the piston upwards and compresses the gas. This increases the gas pressure. However, this increase is limited, and the pressure in the line gradually settles down to a normal level.

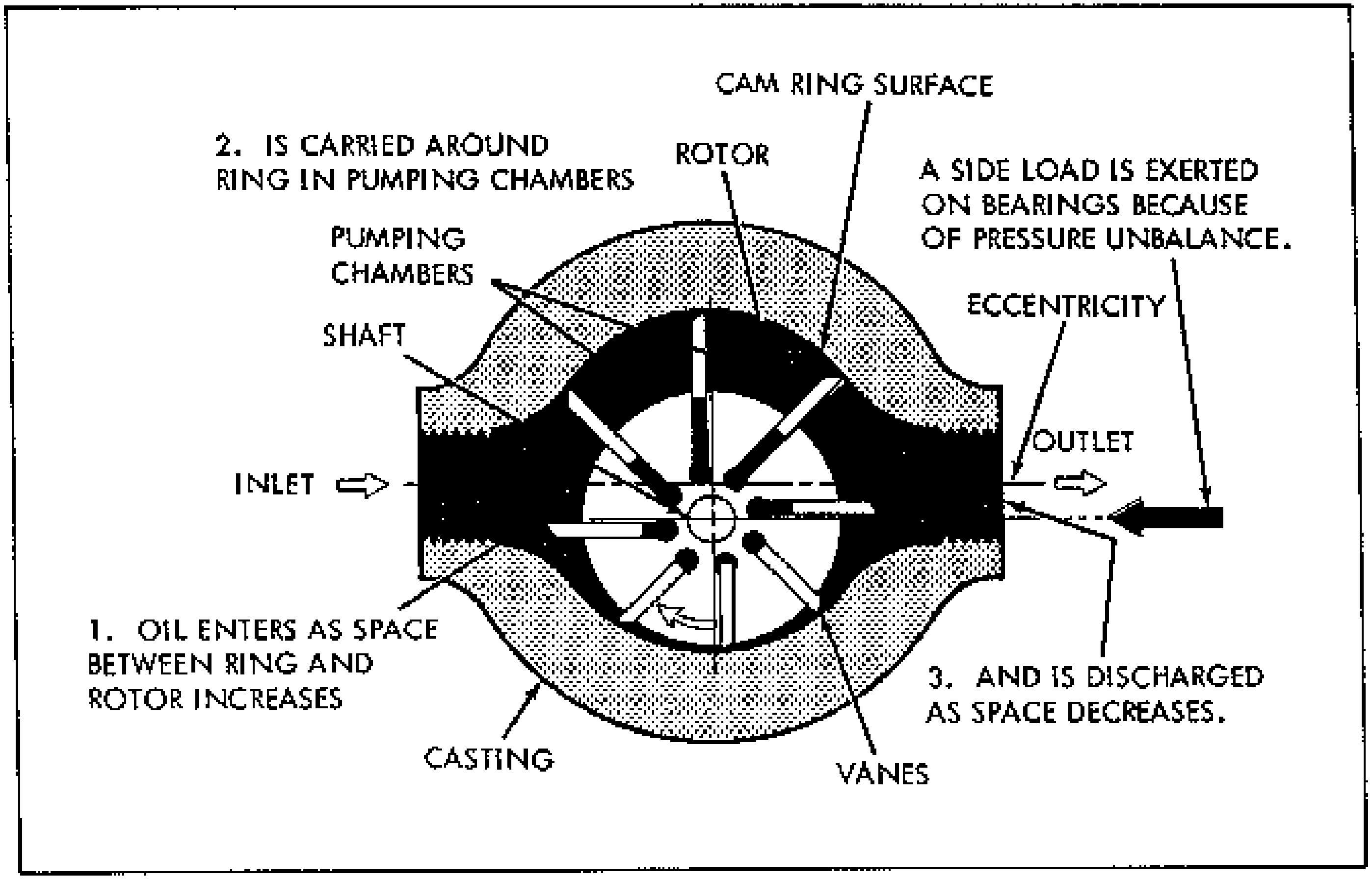

GAS VALVE
LOCK NUT
SAFETY FUSE
SPLIT RING
END CAP
"O" RINGS
SEAMLESS STEEL HOUSING
COMPACT OPEN DESIGN
"O" RING
BALANCED PISTON
"O" RING
DISCHARGE PORT

Conservation of momentum considerations show that for a wave in a pipe the pressure change ΔP across it is equal to $\rho a \Delta U$ where ΔU is the speed change across it, ρ is the density of the fluid and a is the wave speed for the pipe. One can show that the wave speed is $a=\sqrt{[\mathbf{K}/\rho]}$ where $\mathbf{K}$ is the effective bulk modulus of the pipe. This is $\mathbf{K}=K/[1+[DK]/[Ee]]$ where D is the diameter of the pipe, K is the bulk modulus of the fluid, E is the Elastic Modulus of the pipe wall material and e is the wall thickness. One can estimate the wave speed of a pipe by sending a pulse up the pipe and measuring the wave period T. Theory shows that the wave period T is 4 times the transit time $\mathcal{T}$ for the pipe, which is length of the pipe L divided by wave speed a. Manipulation gives $T=4\mathcal{T}=4L/a$ or $a=4L/T$.

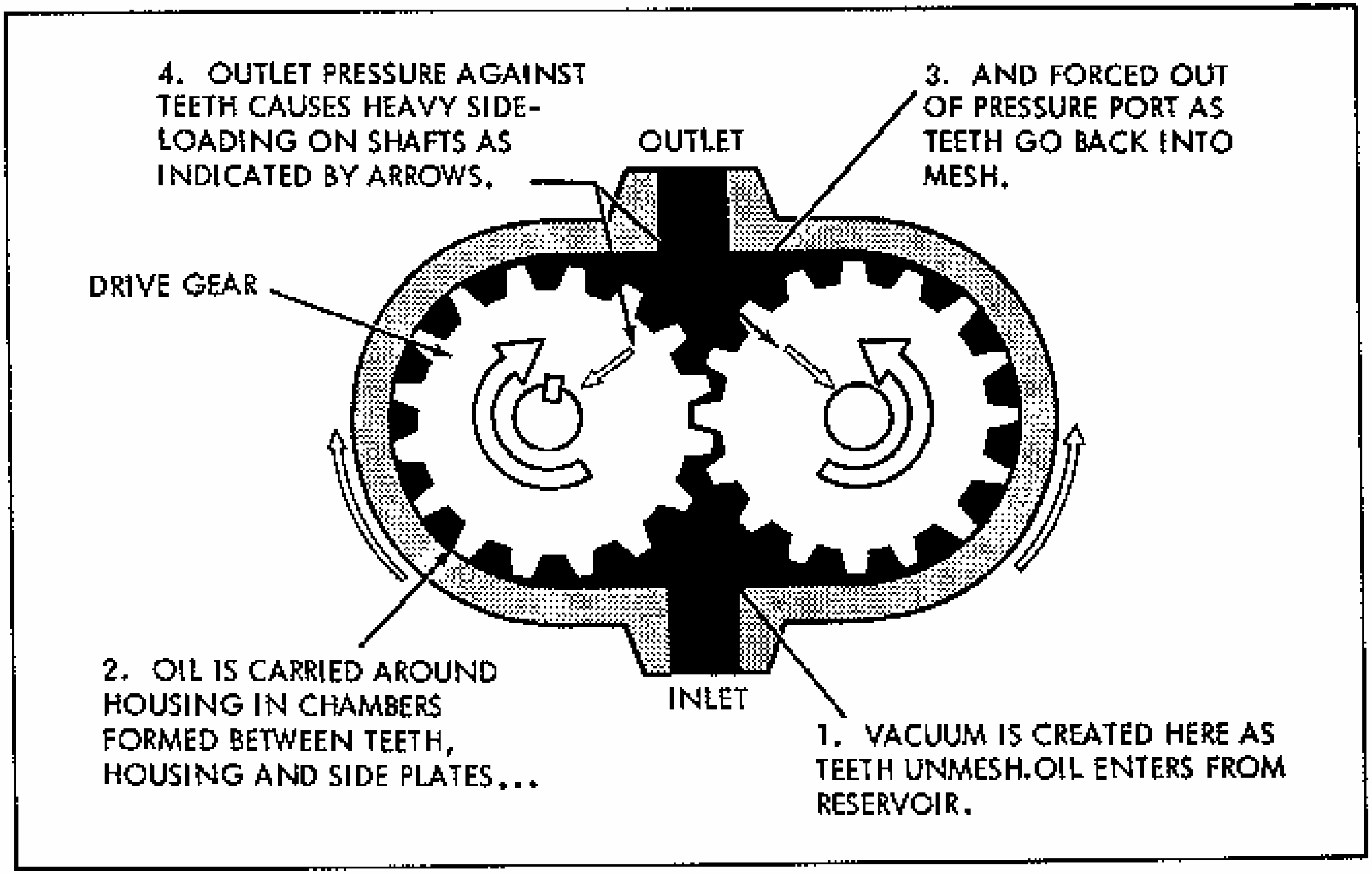
Some schematics of pumps used in hydraulic systems are given below. All are positive displacement devices. This means that, when they are stopped, oil does not back flow through them. Note that some pumps are pressure compensated. This means that, as pressure builds up downstream, components within them move in such a way to limit pressure build up. Usually, when pumps are non compensated, relief valves are used to limit pressure. When pressure reaches a certain level, it forces a spool to move in such a way that a flow path to the sump is created and build up in pressure is stopped. Such a valve is shown in the system sketch. A spring loaded check valve can also be used for this purpose.


Inlet
Outlet
Power Rotor
Ball Bearing
Thrust Cage
Idler Rotor
Balance Piston
Balance Cup
Rotor Housing
Mechanical Seal

SCREW PUMP


CAM RING SURFACE
2. IS CARRIED AROUND RING IN PUMPING CHAMBERS
ROTOR
A SIDE LOAD IS EXERTED ON BEARINGS BECAUSE OF PRESSURE UNBALANCE.
PUMPING CHAMBERS
ECCENTRICITY
SHAFT
OUTLET
INLET
1. OIL ENTERS AS SPACE BETWEEN RING AND ROTOR INCREASES
3. AND IS DISCHARGED AS SPACE DECREASES.
CASTING
VANES

VANE PUMP


4. OUTLET PRESSURE AGAINST TEETH CAUSES HEAVY SIDE-LOADING ON SHAFTS AS INDICATED BY ARROWS.
OUTLET
3. AND FORCED OUT OF PRESSURE PORT AS TEETH GO BACK INTO MESH.
DRIVE GEAR
2. OIL IS CARRIED AROUND HOUSING IN CHAMBERS FORMED BETWEEN TEETH, HOUSING AND SIDE PLATES...
INLET
1. VACUUM IS CREATED HERE AS TEETH UNMESH.OIL ENTERS FROM RESERVOIR.

GEAR PUMP

A schematic of the hydraulics setup in the engineering building at MUN is shown below. This supplies high pressure oil to experiments in the structures lab and elsewhere. Note that there are two pumps: one high pressure and one low pressure. Both are screw pumps. Note also the accumulator and filters in the hydraulic lines.