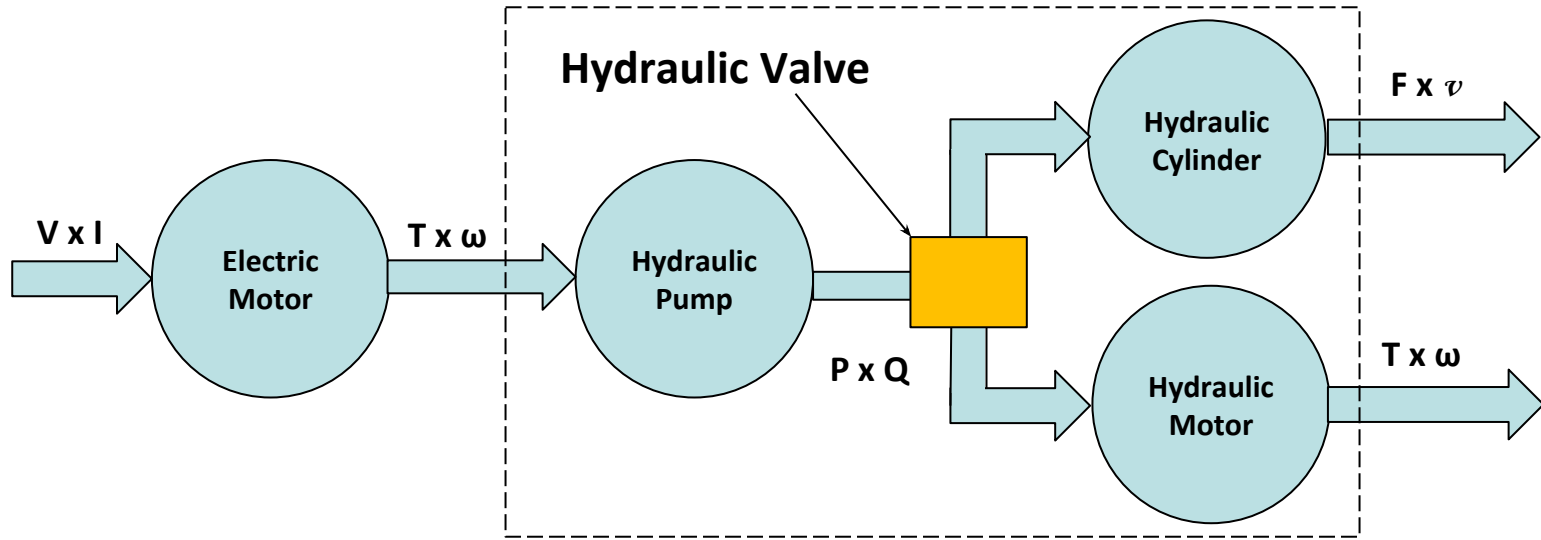


Hydraulic Valves

Introduction

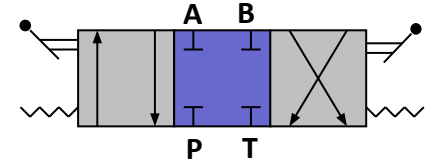
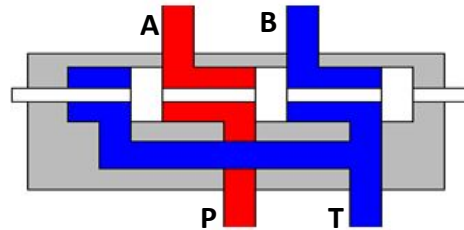
- Hydraulic valves are those elements that control the direction and amount of fluid power in a circuit. They do this by controlling the pressure and the flow rate in various sections of the circuit.



Types of Hydraulic Valves

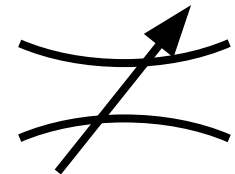
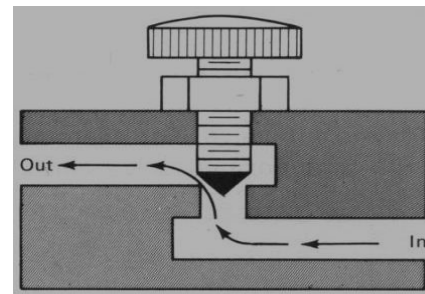
- **Directional Control Valve:**

Control the direction of flow of the hydraulic fluid to different lines in the circuit



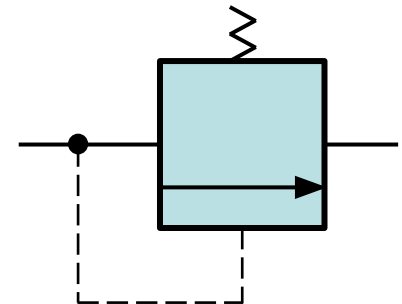
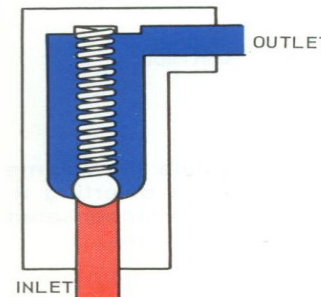
- **Flow Control Valves:**

Control the amount of fluid flow in the circuit

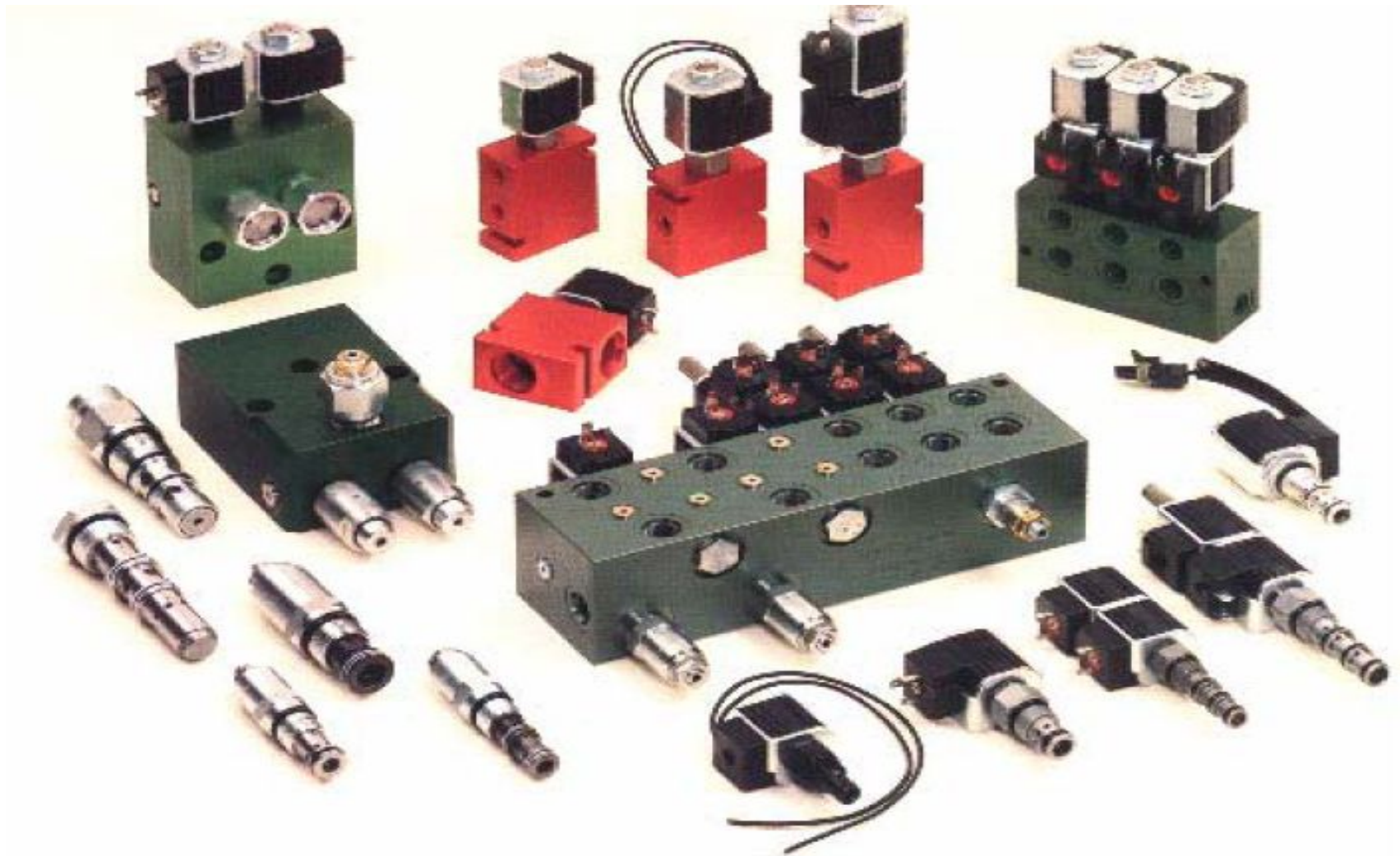


- **Pressure Control Valves:**

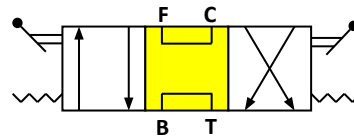
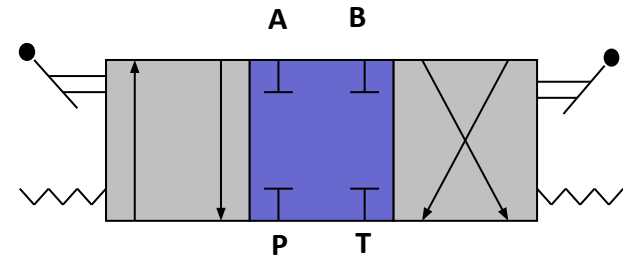
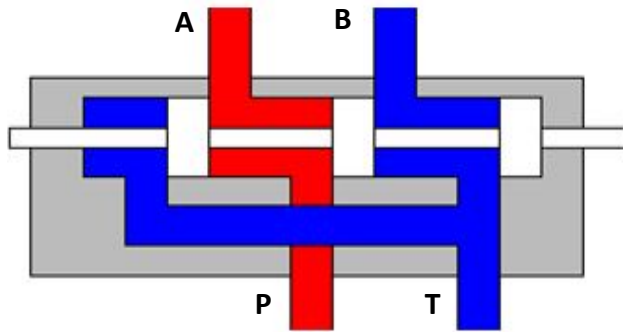
Control the pressure in different segments in the circuit

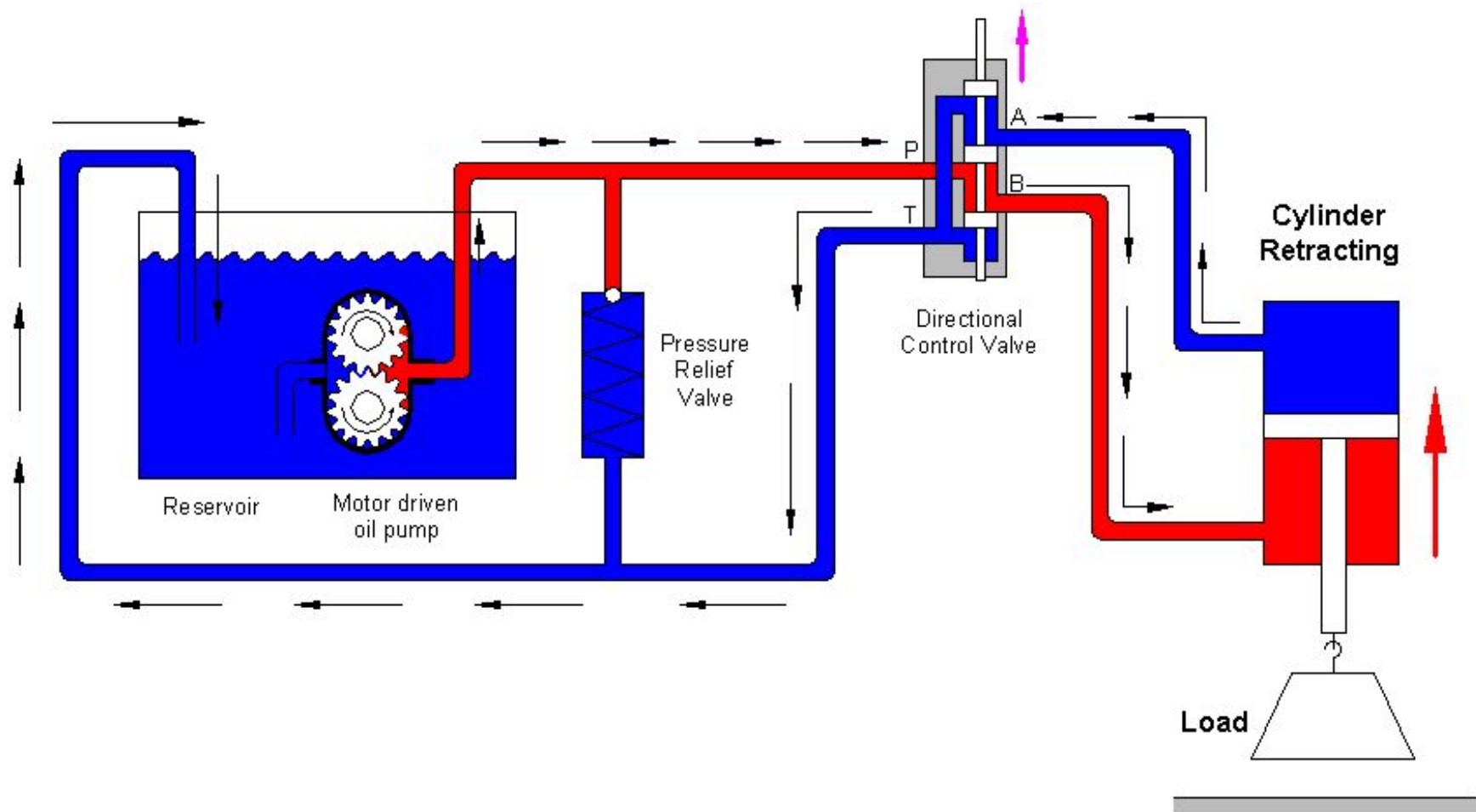


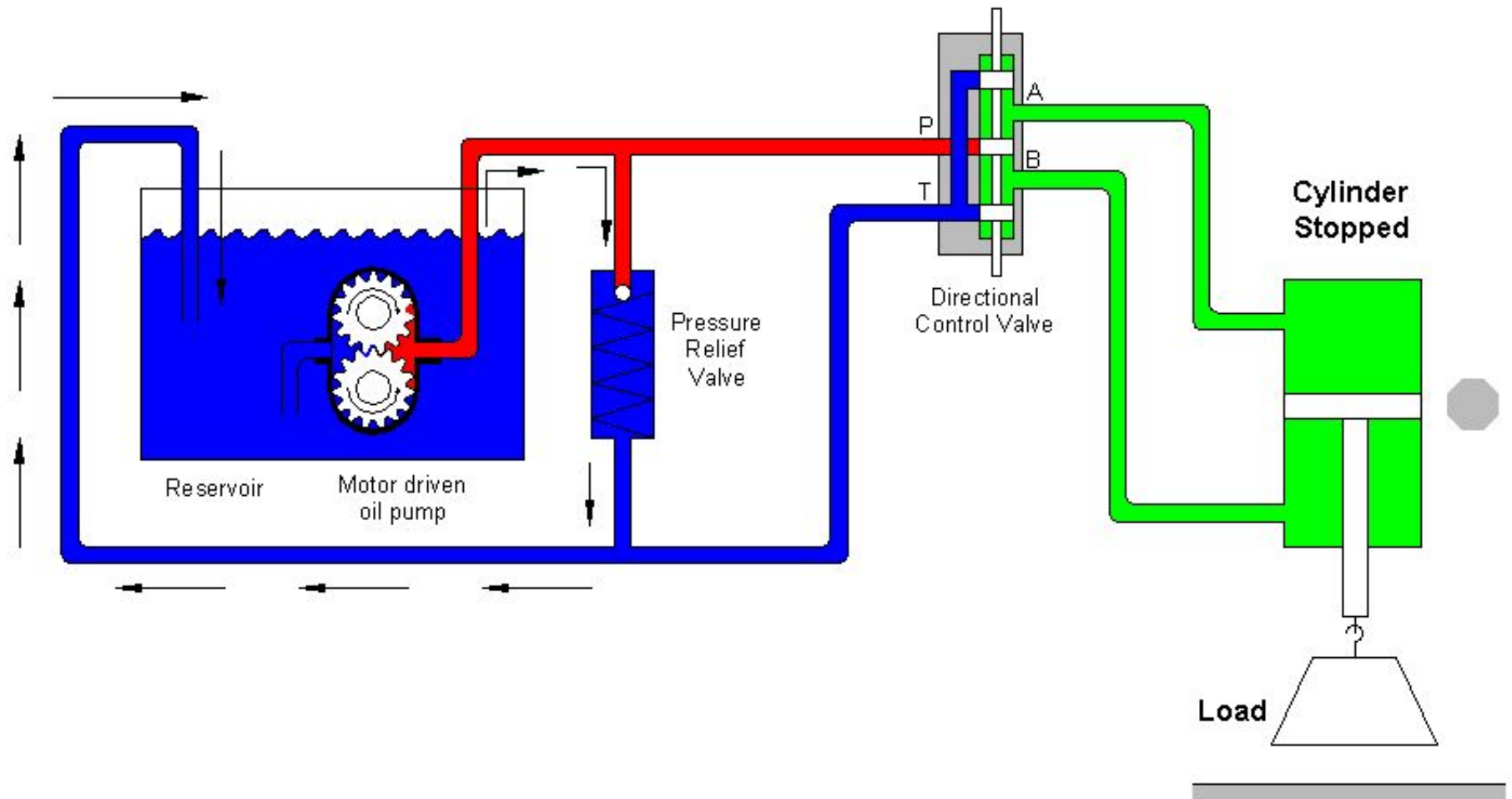
Types of Hydraulic Valves

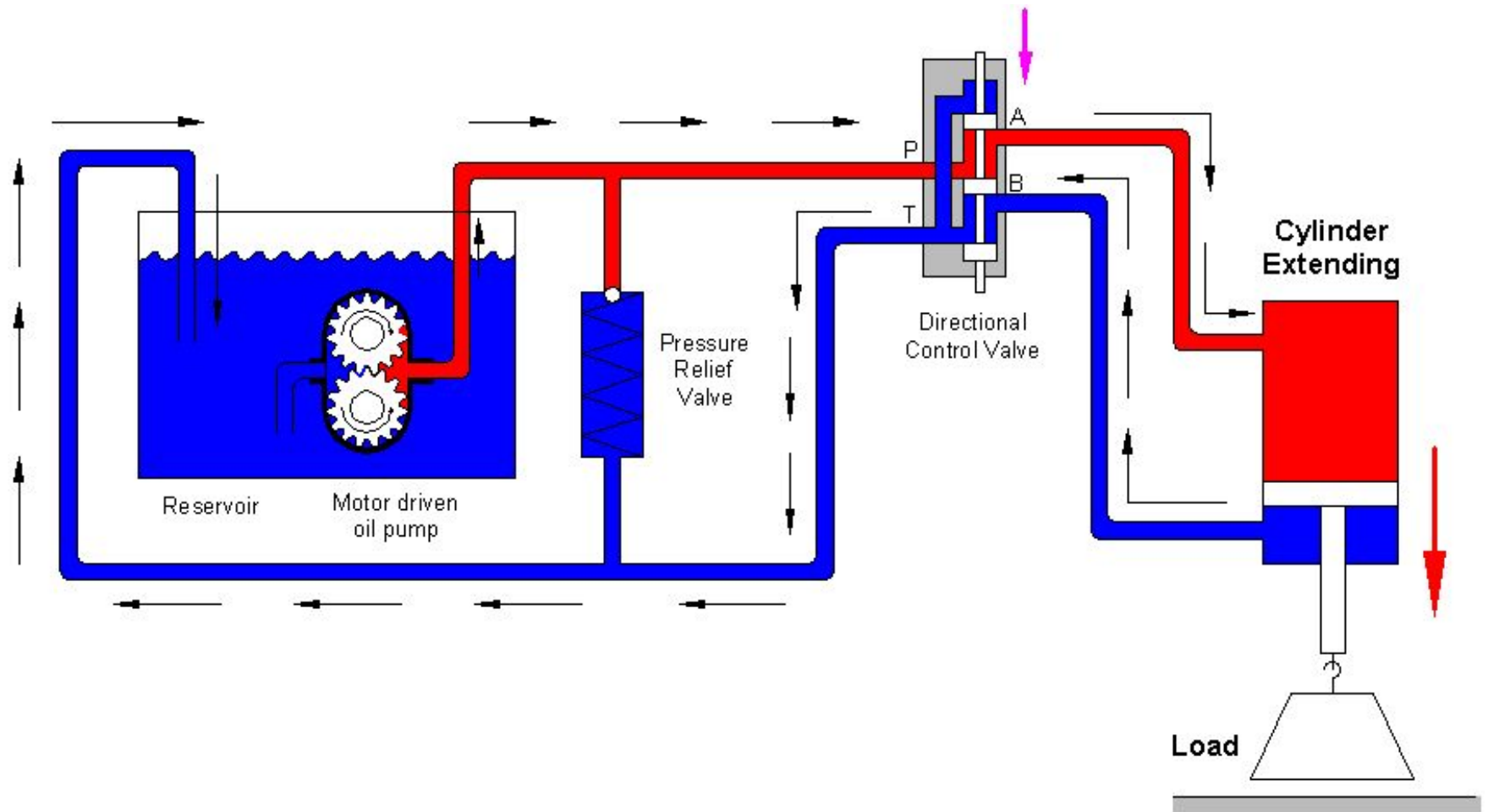


Directional Control Valves



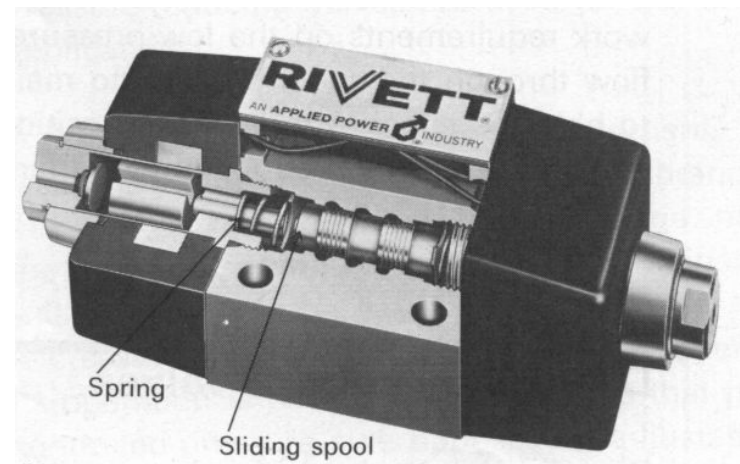
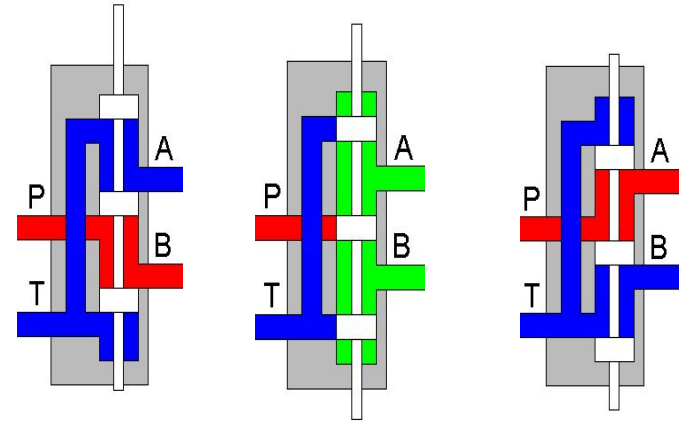






Directional Control Valves

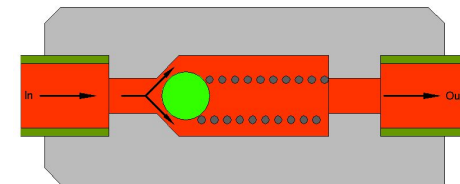
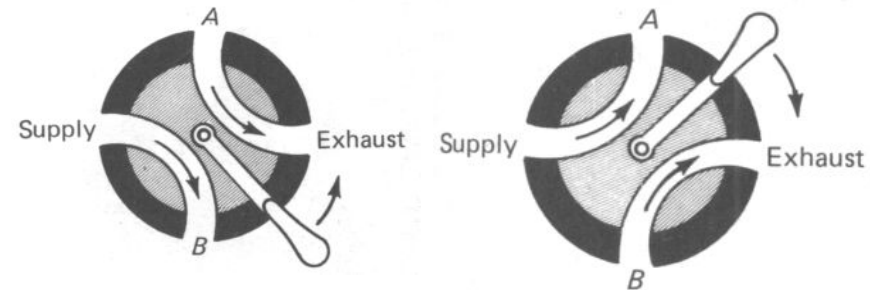
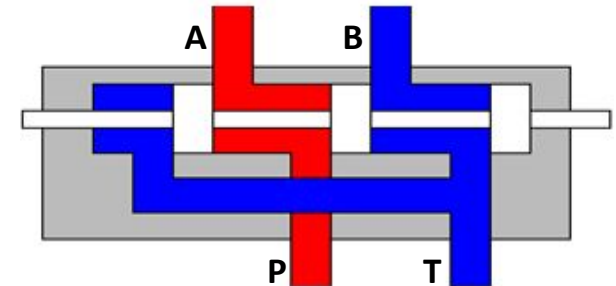
- Directional control valves are used to direct inlet flow to a specific outlet ports
- They can be classified according to the following:
 - **Internal control element structure**
 - **Number of ports or ways**
 - **Number of positions**
 - **Method(s) of actuation**
 - **Center position flow pattern.**



Directional Control Valves:

Internal Element Structure

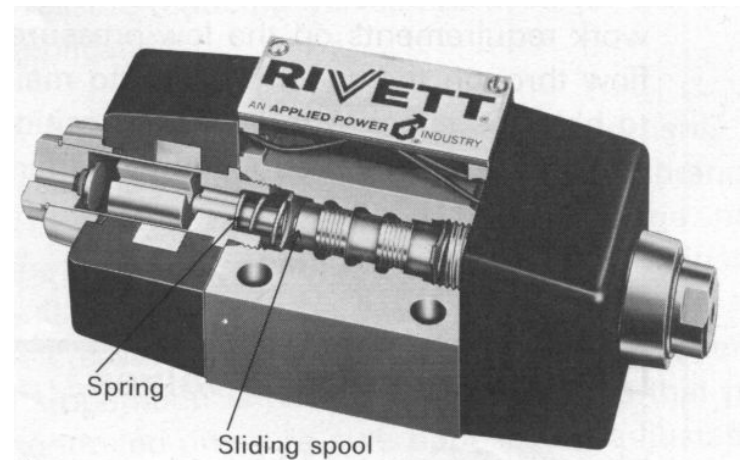
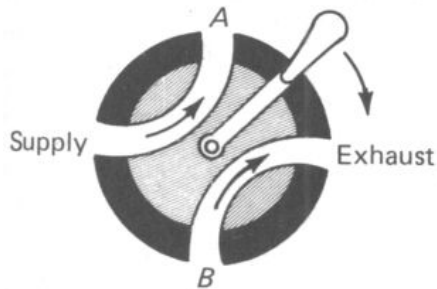
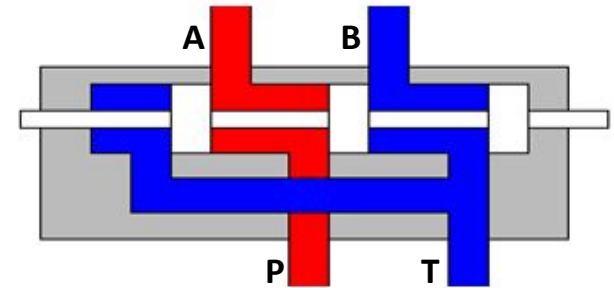
- The internal control element in directional valves may be a sliding spool, rotary spool, poppet or ball.
- The constructional design of the element makes certain classes particularly suitable to specific circuit applications and conditions. of flow.



Directional Control Valves:

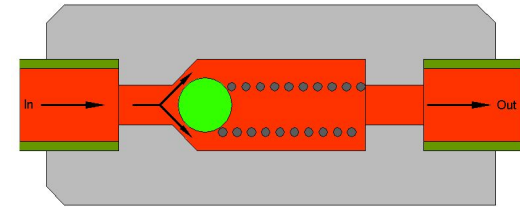
Internal Element Structure

- The *sliding spool* valve has a spool fitted inside the valve body. Moving the spool linearly varies the direction of fluid flow.
- The spool in the *rotary spool* valve rotates to change the direction of flow.

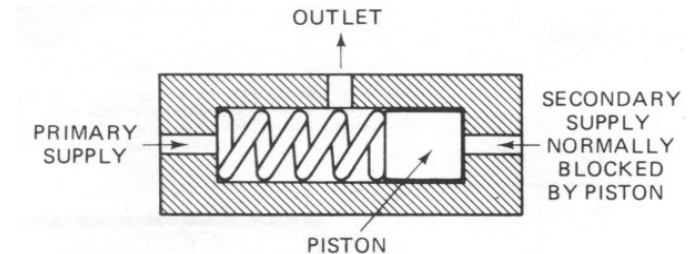


Directional Control Valves: Ways or Ports

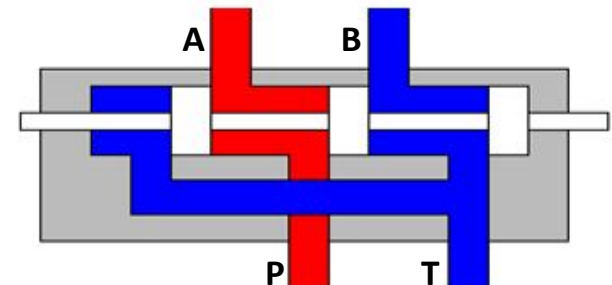
- The number of ports in a directional control valve is identified by the term **way**. Thus, for example, a valve with four ports is a four-way valve.
- *Two-way valves* have two working ports. They are used either to open or to close a path for flow in a single line. A check valve is an example on a **two-way** valve.
- A *three-way valve* has three working ports. It can have one inlet and two outlets or two inlets and one outlet.
- *Four way valves* have four connections to the circuit. The designations P for pressure, T for tank, and A and B for ports on either end of the cylinder are commonly used on four-way valves.



Two-Way Valve e.g. check valve



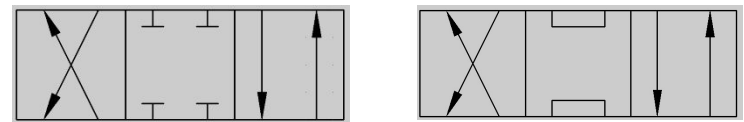
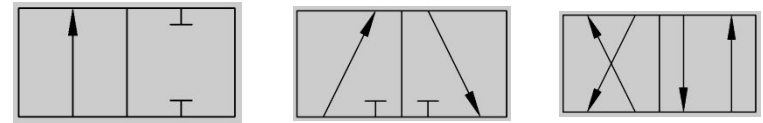
Three-Way Valve e.g. Shuttle Valve



Four-Way Directional Control Valve

Directional Control Valves: Positions

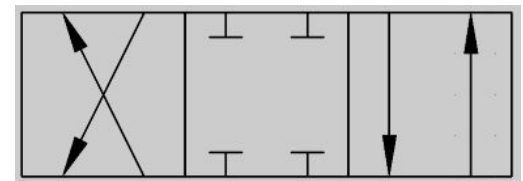
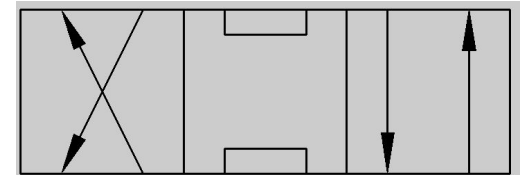
- The positions in a directional control valve determines the number of alternative flow conditions the valve can provide.
- Two-position valves provide two different flow conditions. Open or closed passages from the inlet ports to the outlet ports are changed in each position.
- A three-position valve provides three different flow conditions between its ports.



Directional Control Valves:

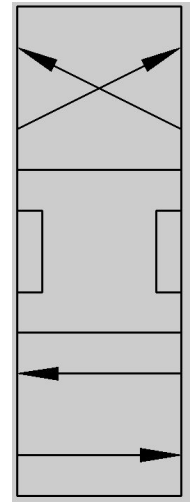
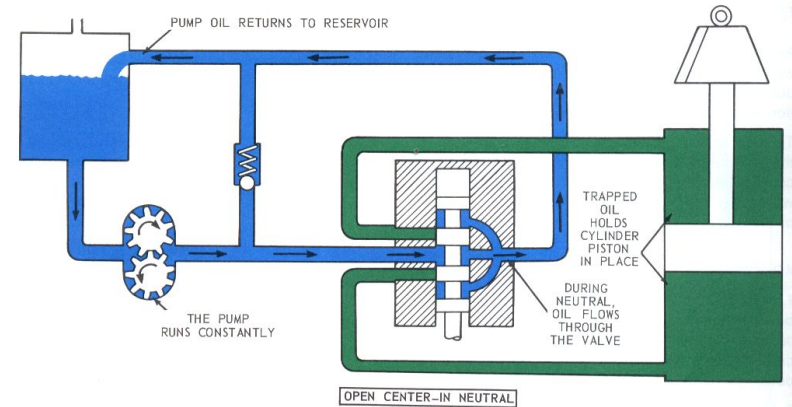
Center Position Flow Patterns

- There are several variations in the flow pattern of the center position of a three-way valve. These are made possible by the configuration of the spool. The center configuration affects the circuit behavior when the valve is placed in the center neutral position.
- Open center valves allow pump oil to flow through the valve during neutral and return to the tank. Opening the cylinder ports in the center neutral positions causes the cylinder to float.
- Closed center valves stop the flow of oil from the pump during neutral. Normally, the cylinder ports are also blocked when a spool is in neutral, which locks the cylinder in position.



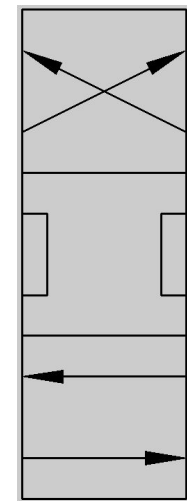
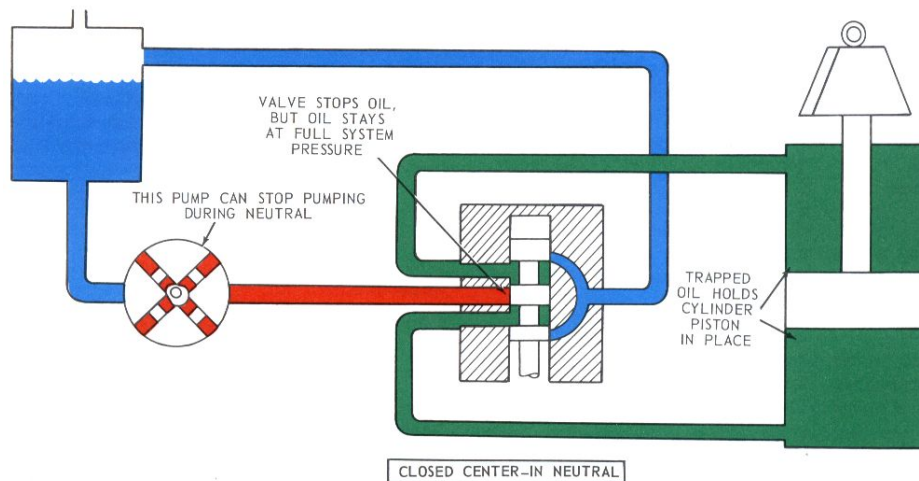
Open – Center vs. Closed – Center Systems

- In an open – center valve, the pump usually supplies a constant flow of oil, and the oil must have a path for return when it is not required to perform a work. The pressure head on the pump is due to the head losses in the pipe, and is relatively small.
- An open – center system is the simplest and least expensive for applications which have only a few functions.



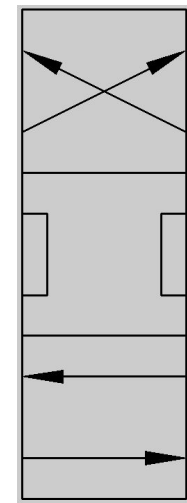
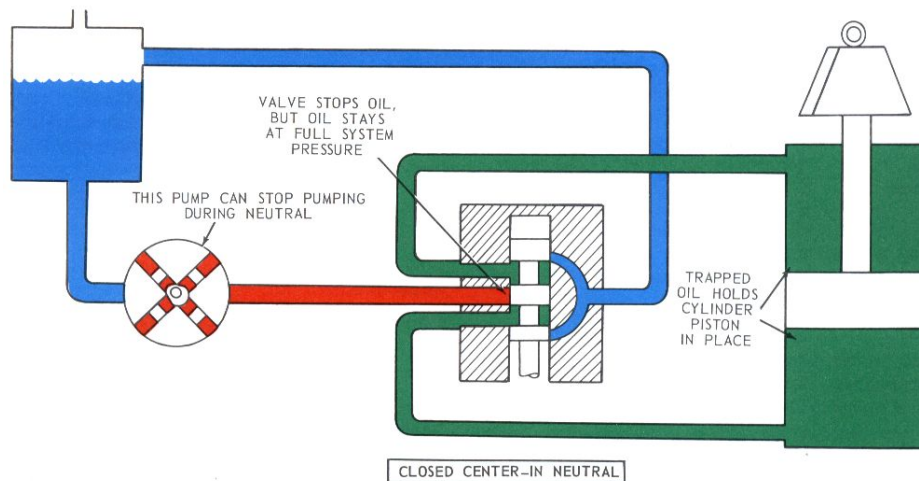
Open – Center vs. Closed – Center Systems

- In a closed – center system, the pressure head on the pump becomes large, and there could be a large waste in power if the pump keeps working at its rated discharge flow rate.
- It is usual in closed – center systems to use a variable displacement pump, which adjusts its flow rate according to the pressure head acting on it. This allows the pump to work in a more efficient mode when the valve is at the center position.



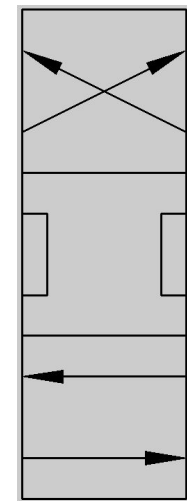
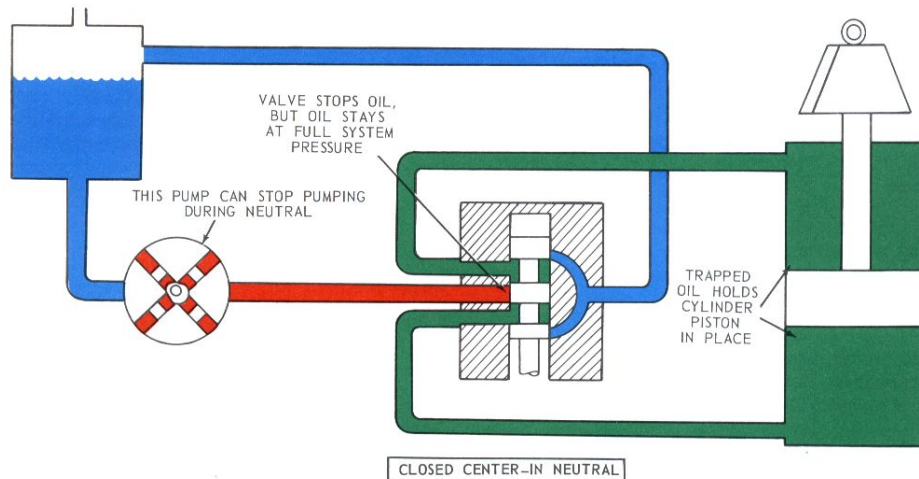
Open – Center vs. Closed – Center Systems

- Today's machines need more hydraulic power and the trend has been towards closed – center systems. In a tractor, for example, oil is required to power the steering, the brakes, the hitch, the loader and other equipment.
- As more functions are added, with varying demands for each function, the open – center system requires the use of flow dividers to proportion the oil flow to these functions. This reduces the efficiency and results in heat build-up.



Open – Center vs. Closed – Center Systems

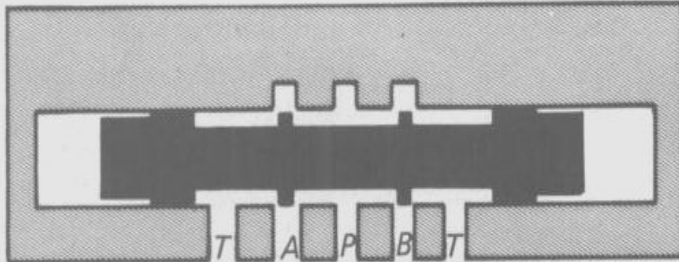
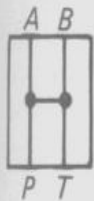
- There is no requirement for a relief valve in a basic closed – center system employing a variable displacement pump. The pump simply operates in a zero flow rate mode, which prevents heat build-up due to flow through a pressure relief valve.
- Closed – center systems employing a variable displacement pump are more efficient, particularly in applications requiring force but little displacement such as power brakes. It allows pump pressure to be constantly applied to brake piston, while the pump is in standby mode.



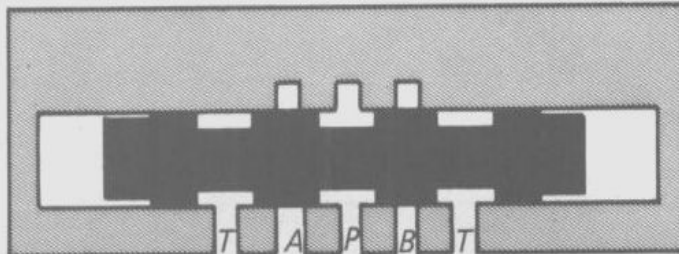
Directional Control Valves:

Center Position Flow Patterns

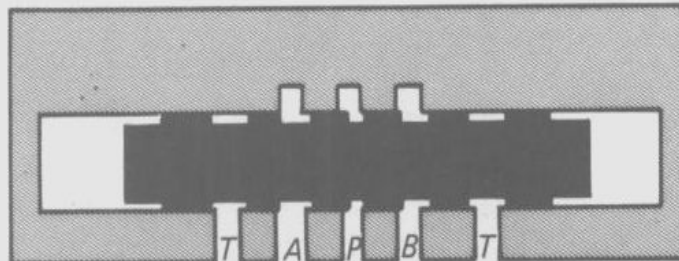
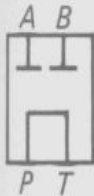
ANSI
symbols



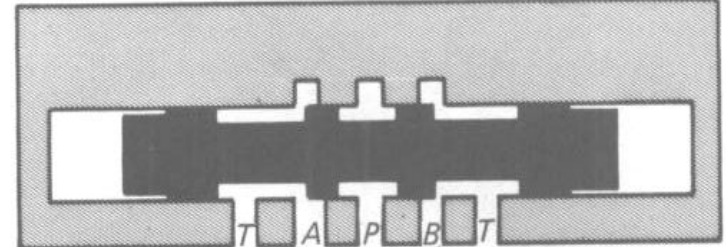
Open center (All ports open to each other)



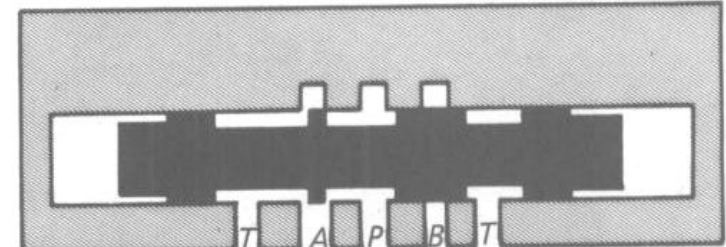
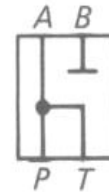
Closed center (All ports closed)



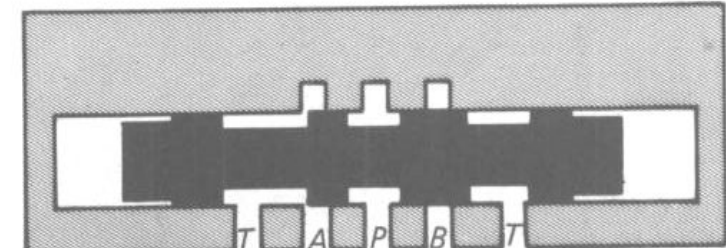
Tandem



Closed (A & B open to T)



B closed (P open to T thru A)



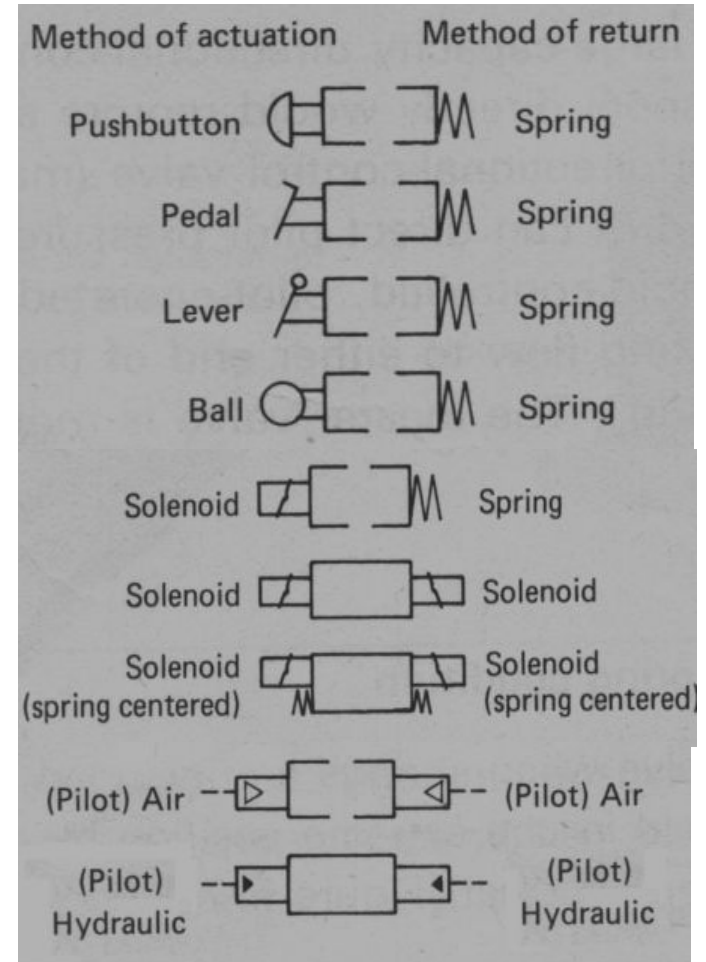
P and B closed (A open to T)

Directional Control Valves:

Method of Actuation

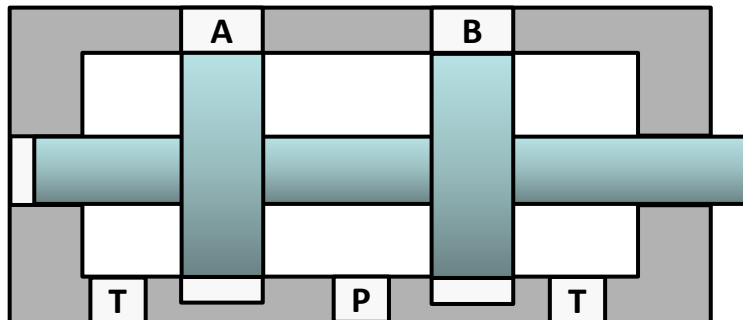
- The methods of actuation refer to the various means by which the valve element is moved from one position to another. The different methods available to actuate the valve include

- Manual Actuation
 - Push button
 - Lever
 - Pedal
- Mechanical Actuation
 - Spring
 - Ball and Cam
- Fluid (Pilot)
 - Air (pneumatic)
 - Oil (hydraulic)



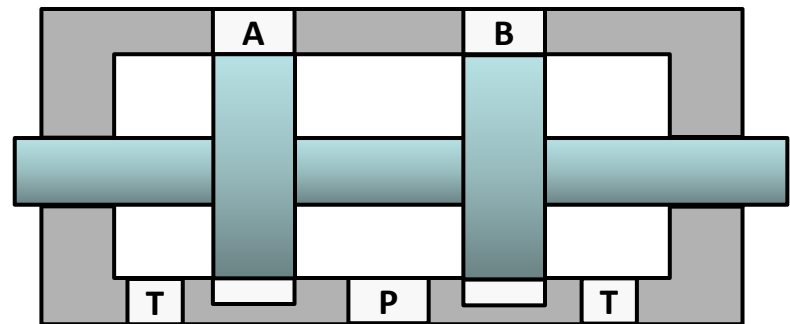
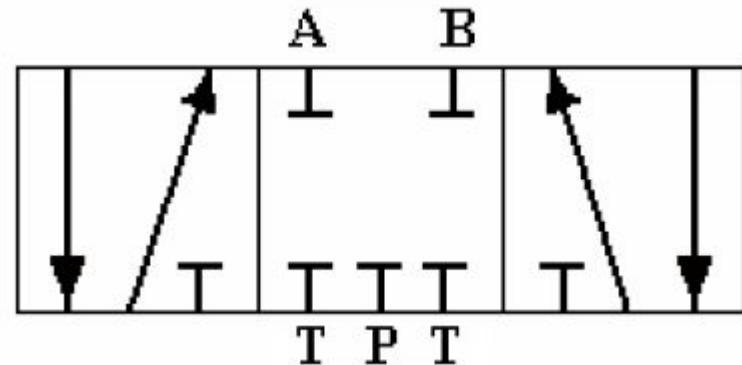
Example 1

- For the directional control valve shown, identify the following:
 - Internal control element
 - Number of ways
 - Number of positions
 - Center position flow pattern
 - Sketch the symbol of the valve

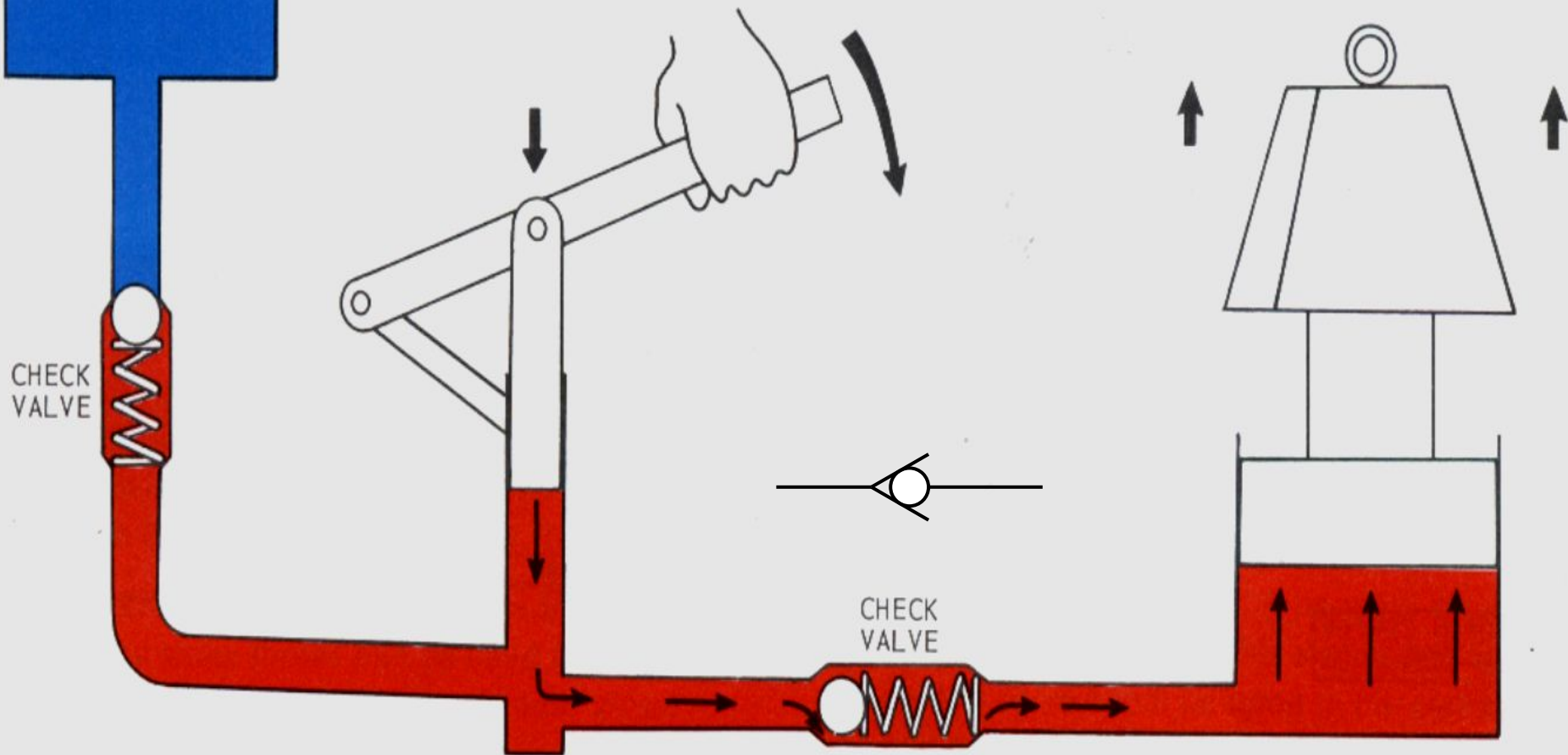
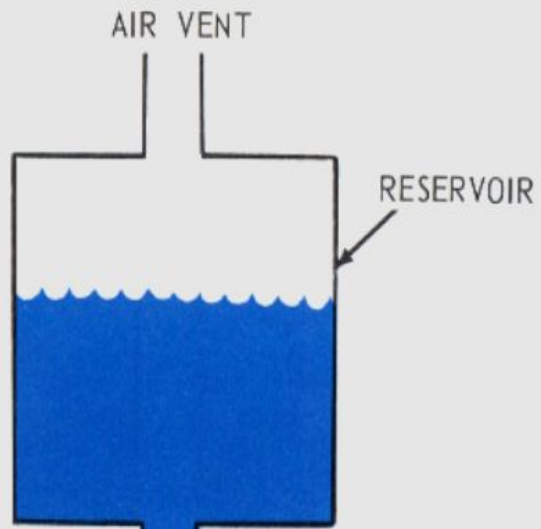


Example 1: Solution

- For the directional control valve shown, identify the following:
 - Internal control element: Spool
 - Number of ways: 5
 - Number of positions: 3
 - Center position flow pattern: Closed
 - Sketch the symbol of the directional control valve shown identifying the flow paths in each envelope

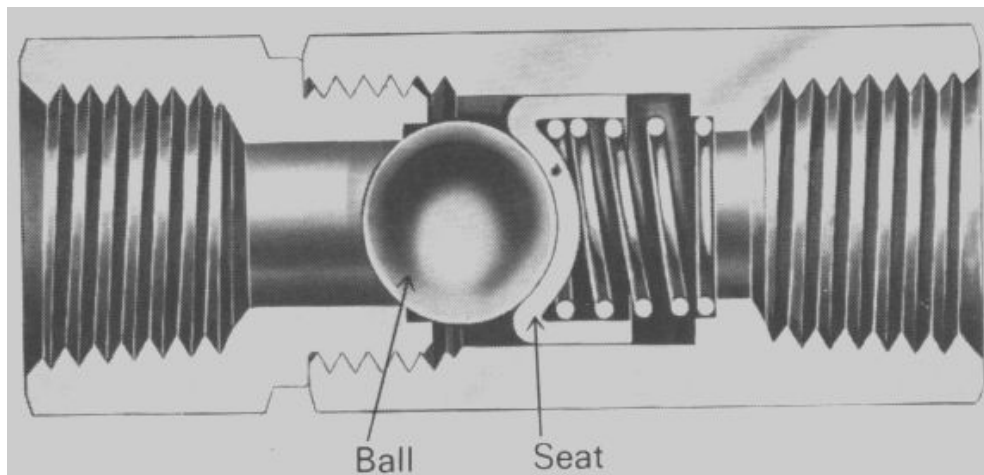
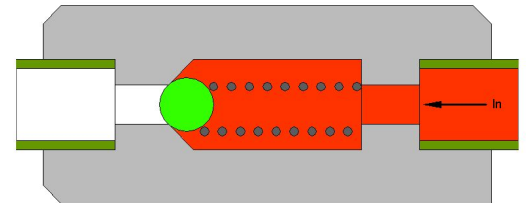
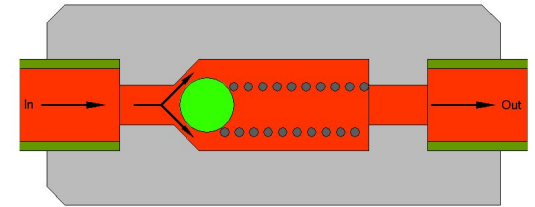


Check Valves



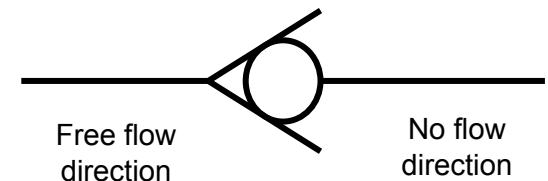
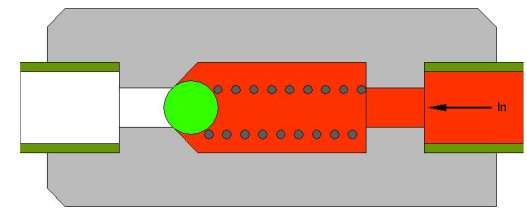
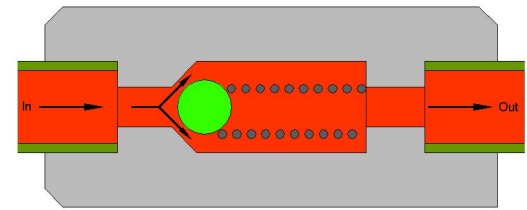
Check Valves

- The simplest type of a direction control valve. It permits flow in one direction, and prevent any flow in the opposite direction. **A check valve is a two-way, two-positions valve.**
- In a ball type check valve, a light spring holds the ball in the closed position. In the free-flow direction, small fluid pressure overcomes the spring force, and flow is allowed.



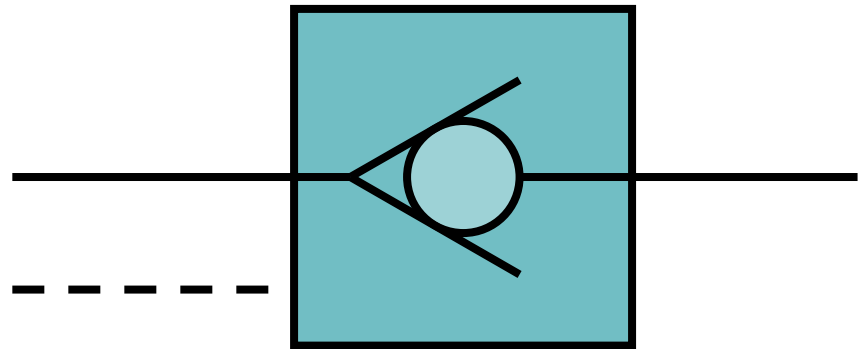
Check Valves

- If flow is attempted in the opposite direction, fluid pressure pushes the ball (along with the spring force) to the closed position. Therefore, no flow is permitted.
- The higher the pressure, the greater will be the force pushing the poppet against the seat. Thus increased pressure will not result in any tendency to allow flow in the non-flow direction.
- The function and the free-flow directions of the check valve are implied in its symbolic representation.



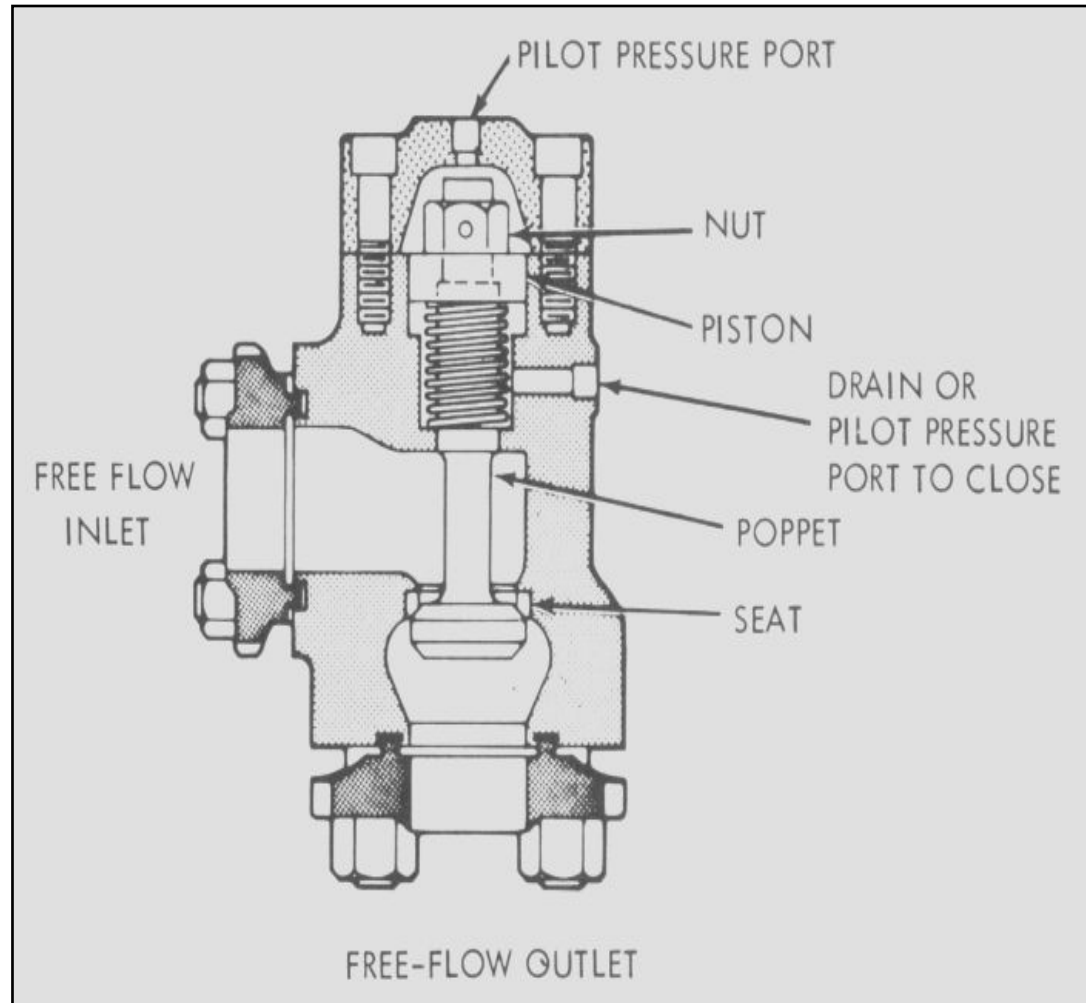
Pilot Operated Check Valves

- A pilot operated check valve always permits free flow in one direction, and permits flow in the normally blocked direction if pilot pressure is applied to the pilot pressure port of the valve.
- The dashed line in the symbol represents the pilot pressure line connected to pilot pressure port of the valve.



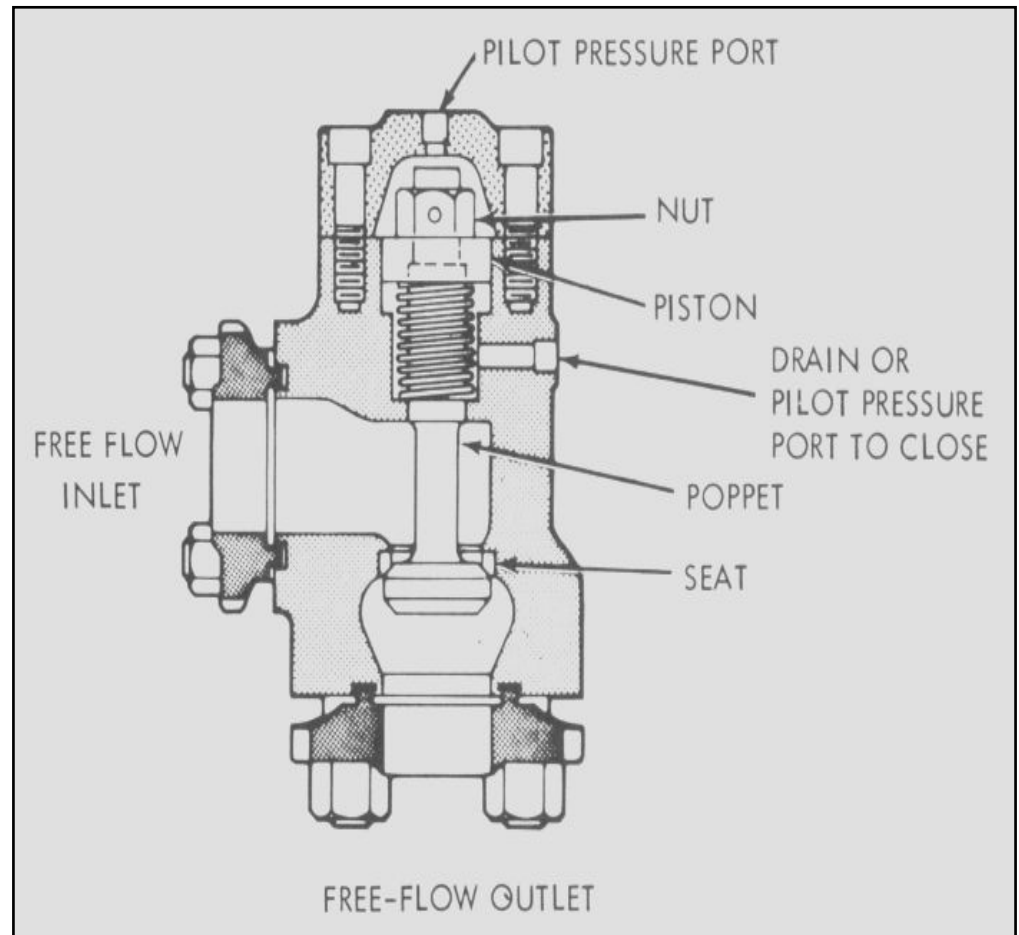
Pilot Operated Check Valves

- In the design shown, the check valve poppet has the pilot piston attached to the threaded poppet stem by a nut. The light spring holds the poppet seated in a no-flow condition by pushing against the pilot piston.
- The purpose of the separate drain port is to prevent oil from creating a pressure buildup on the bottom of the piston.



Pilot Operated Check Valves

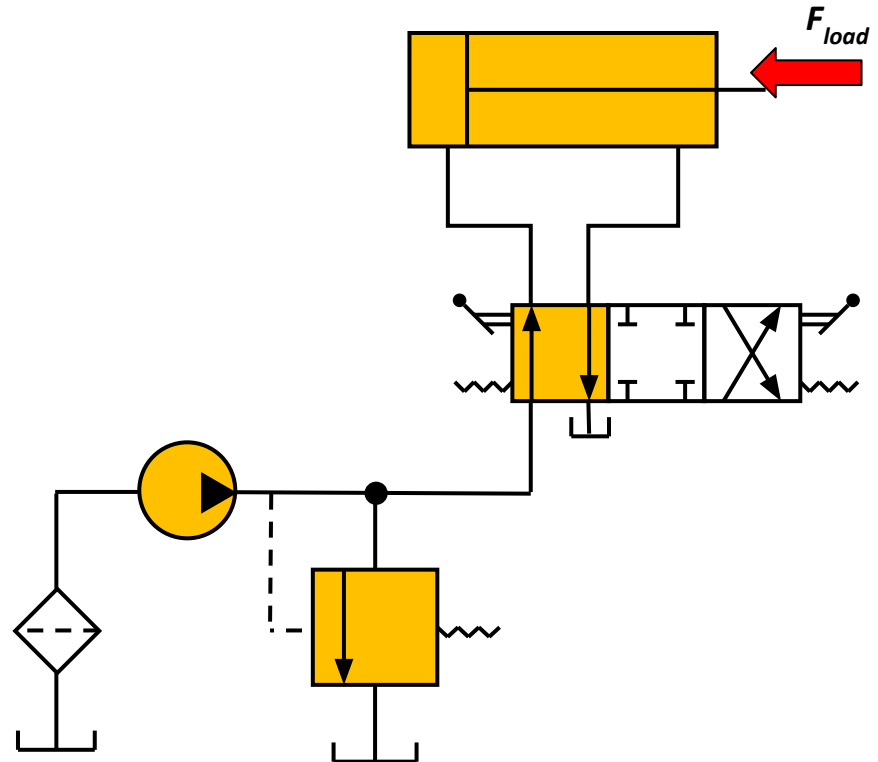
- In the design shown, the check valve poppet has the pilot piston attached to the threaded poppet stem by a nut. The light spring holds the poppet seated in a no-flow condition by pushing against the pilot piston.
- The purpose of the separate drain port is to prevent oil from creating a pressure buildup on the bottom of the piston.



Example 2

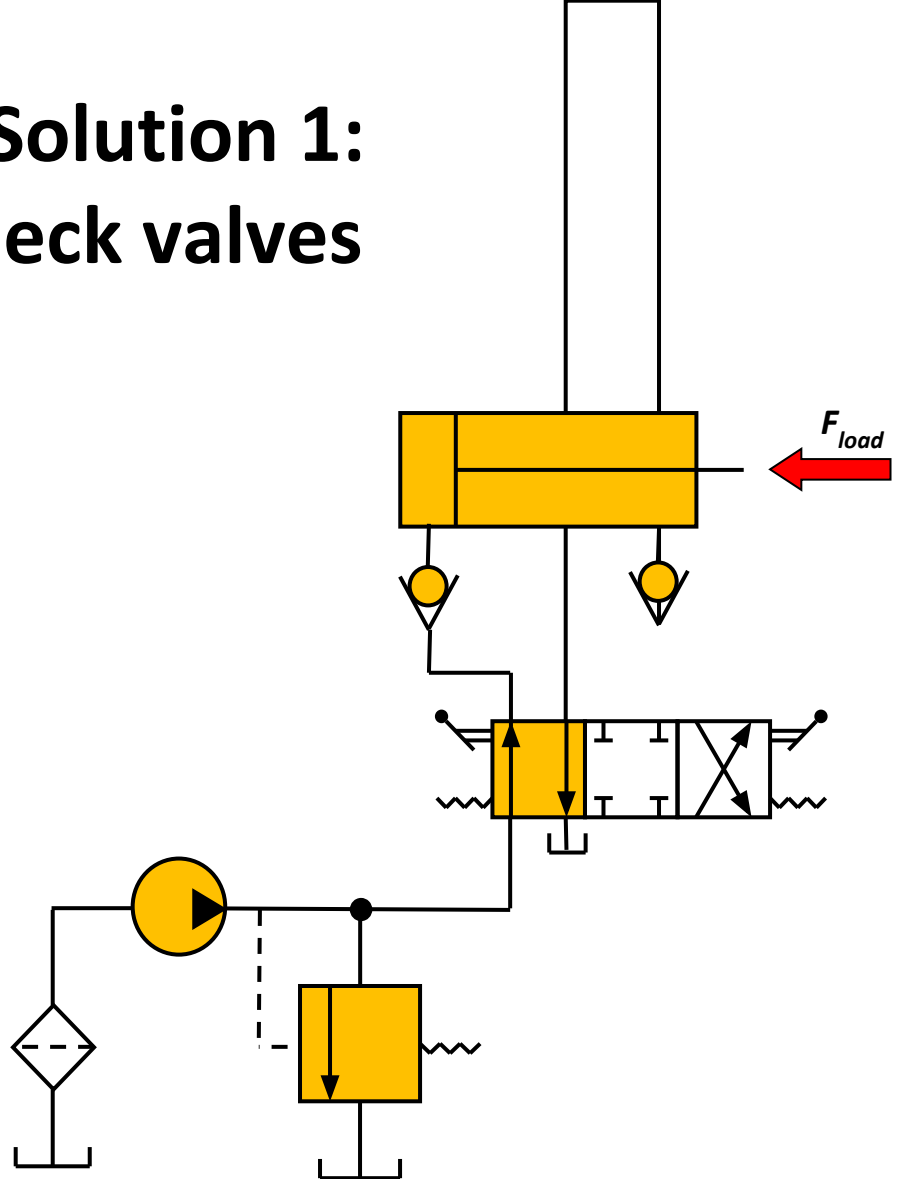
The figure shows a preliminary setup for a hydraulic system utilizing a double acting cylinder for moving a bidirectional load.

1. From a safety point of view, what problem does this system have? What happens in case of hydraulic line rupture, pump failure, or electrical power shutdown in the position shown?
2. Propose a design update using pilot operated check valves to lock the cylinder in position in case of power failure.



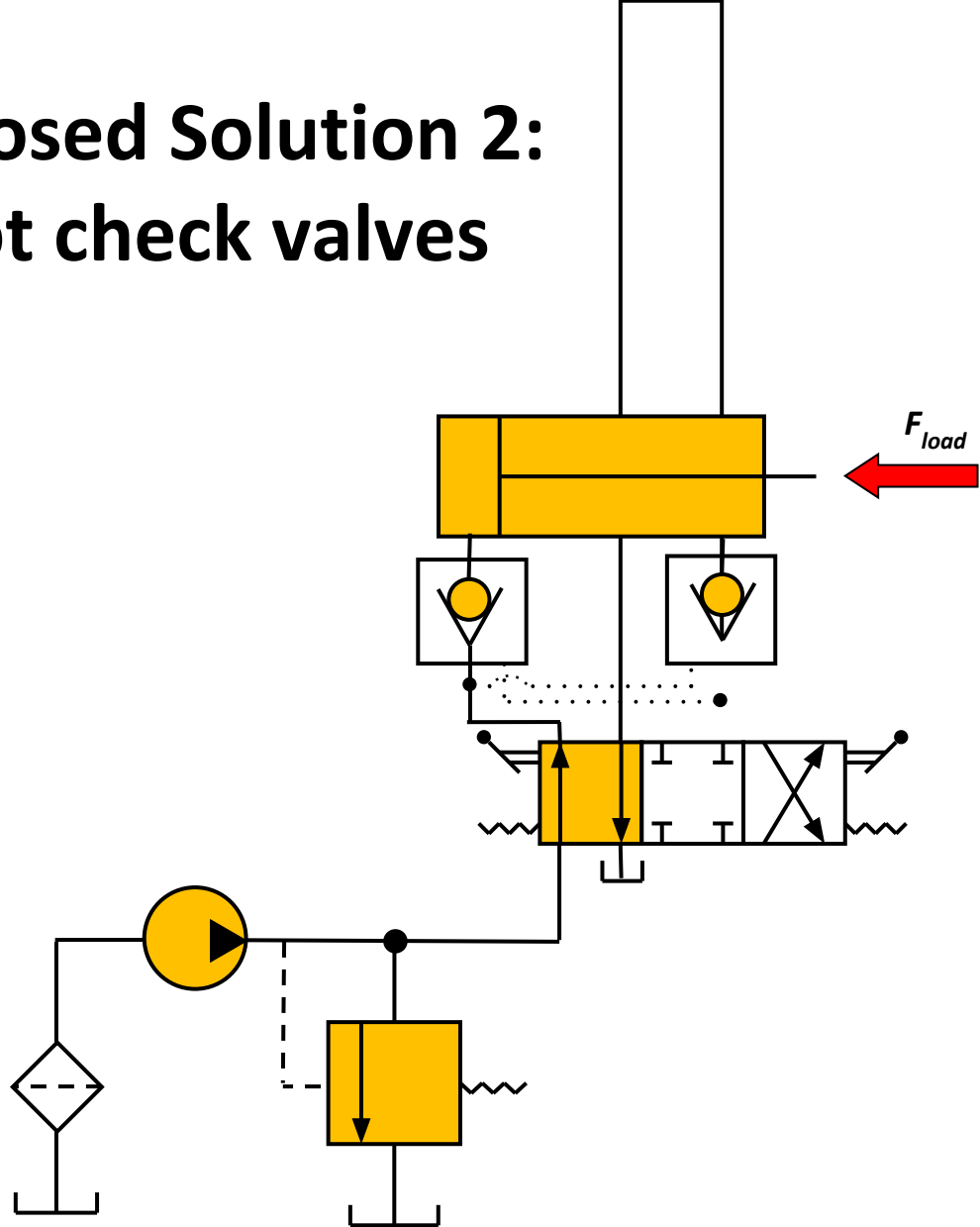
Proposed Solution 1: Regular check valves

Utilizing ordinary check valve would lock the cylinder permanently, disallowing its motion regardless of pump pressure.



Proposed Solution 2: Pilot check valves

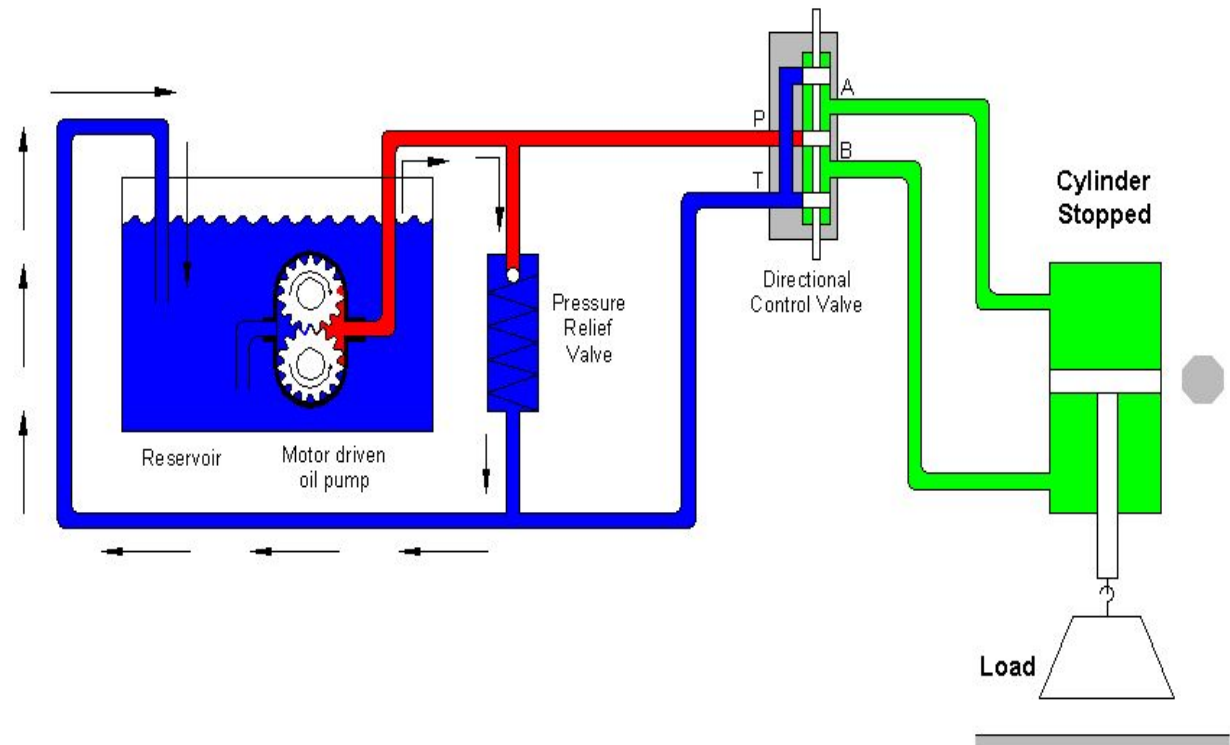
Utilizing pilot check valve would lock the cylinder when failure occurs. When there is enough pump pressure (a sign of normal healthy conditions), the cylinder can be extended or retracted normally.



Pressure Control Valves

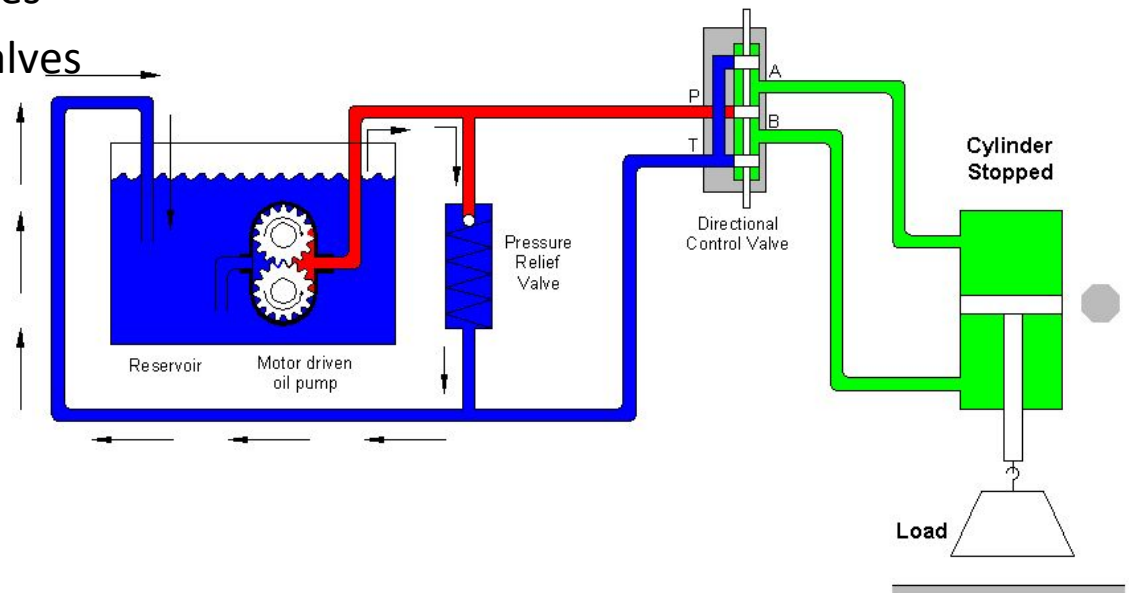
Pressure Control Valves

- Pressure control valves protect the system against overpressure, which may occur due to gradual buildup as fluid demand decreases, or due to sudden surge as valves open or close.
- In hydraulic systems, pressure surges can produce an instantaneous increase in pressure as much as four times the normal system pressure. Shock absorbers are hydraulic devices designed to smooth out pressure surges and to dampen hydraulic shock.



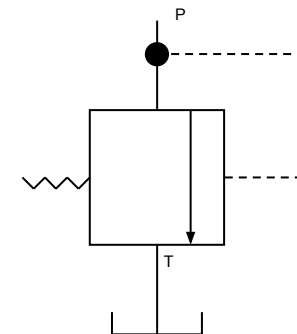
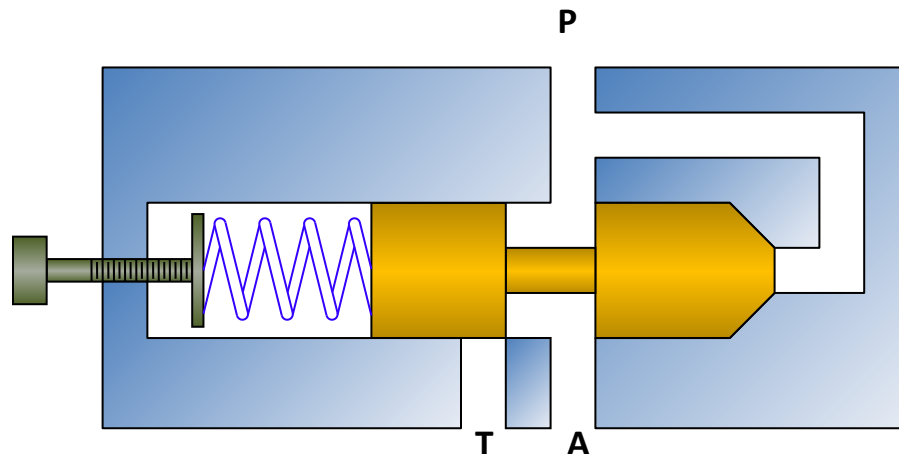
Pressure Control Valves

- The gradual buildup of pressure can be controlled by a pressure compensated pumps. Additionally, the following valve types are used to control fluid pressure:
 - Direct Acting Pressure relief valves
 - Compound Pressure relief valves
 - Unloading valves
 - Sequence valves
 - Counterbalance valves
 - Pressure reducing valves



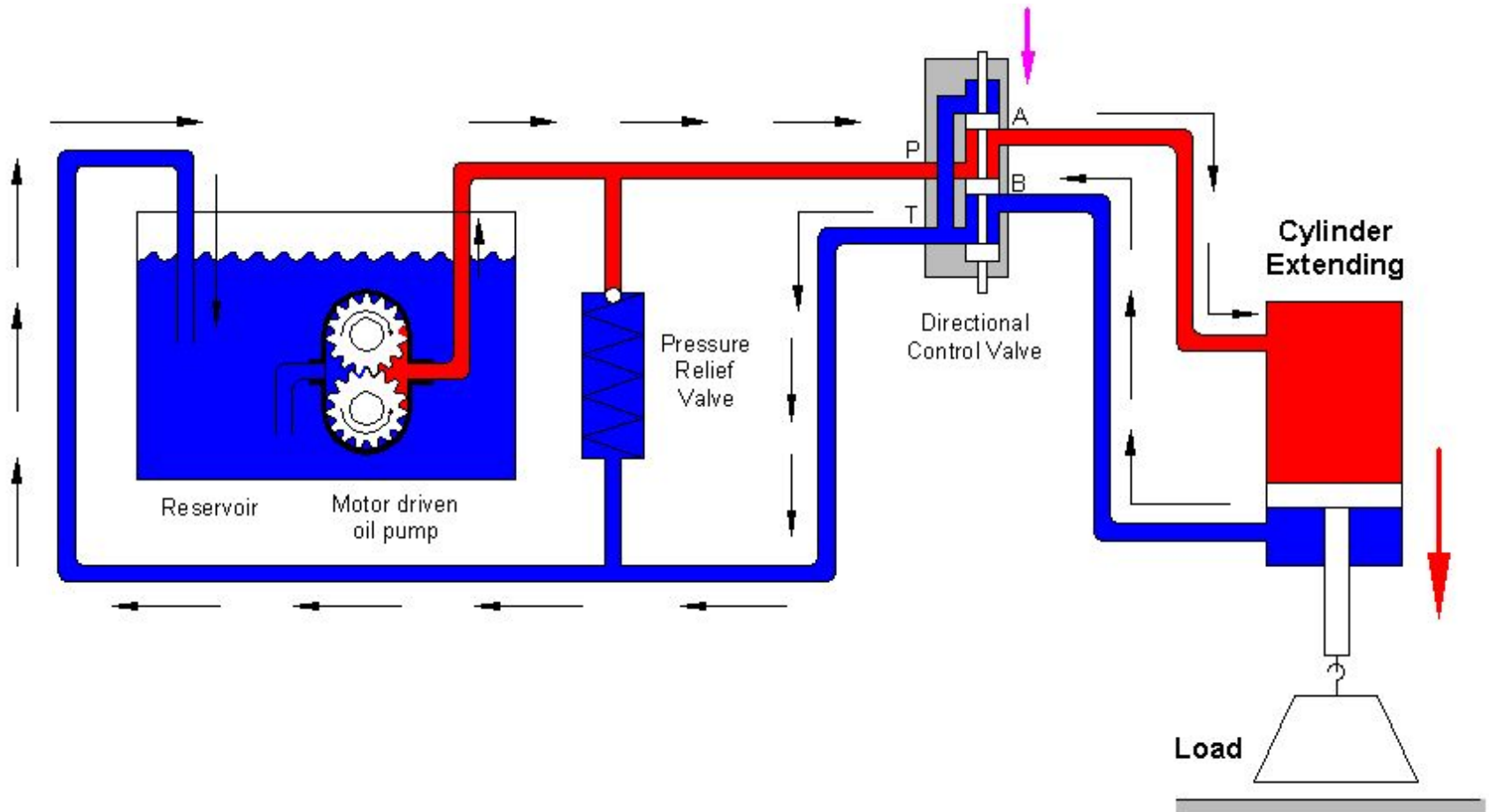
Direct Pressure Relief Valves

- The most widely used type of pressure control valve is the direct pressure relief valve. It is found practically in every fluid power system.
- The direct pressure relief valve is a normally closed valve whose function is to limit pressure to a specified maximum by diverting pump flow back to the tank.
- In a simple pressure relief valve a ball or a poppet is held seated inside the valve by a heavy spring. When the system pressure reaches a high enough, the ball is force off its seat. This permits flow through the outlet to the tank as long as this high pressure is maintained.



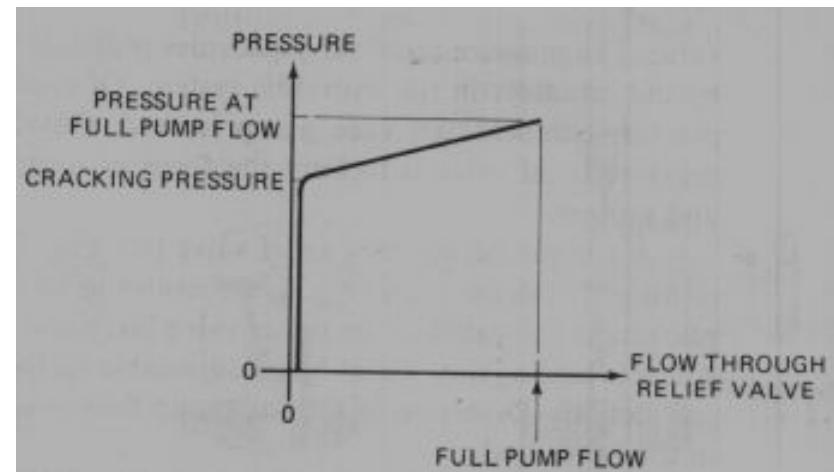
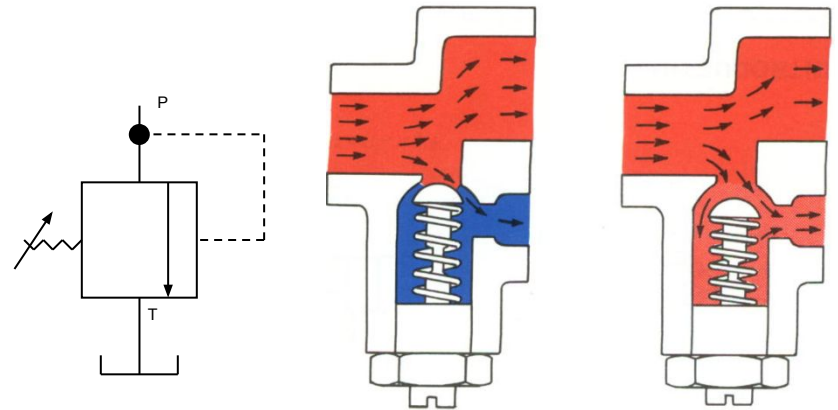
Direct Pressure Relief Valves

- The pressure relief valve provides protection against overload experienced by the actuators in a hydraulic system. One important function is to limit the force or torque produced by the hydraulic cylinders or motors.



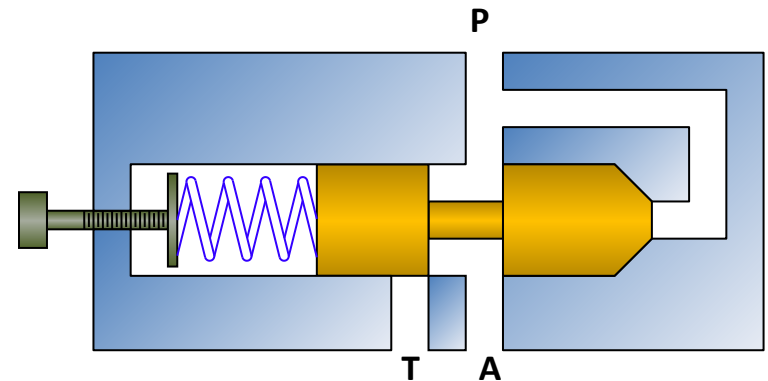
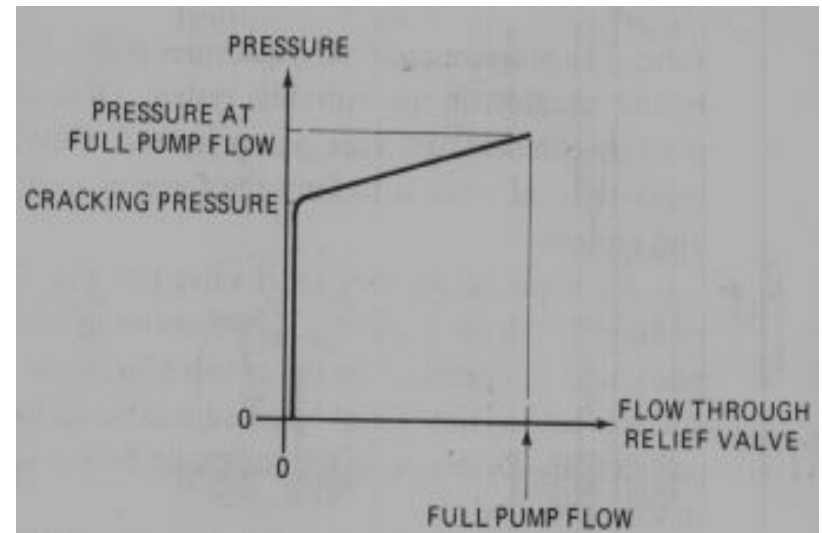
Direct Pressure Relief Valves

- Most pressure relief valves are adjustable. By turning a screw installed behind the spring in or out, the relief valve can be adjusted to open at a certain pressure. The pressure at which the valve begins to open is called the cracking pressure.
- The pressure when the valve opens enough to allow full pump flow can be substantially greater than the cracking pressure. The pressure at full pump flow is the pressure level that is specified when referring to the pressure setting of the relief valve. It is the maximum pressure permitted by the relief valve, and should be set around the maximum working pressure of the system.



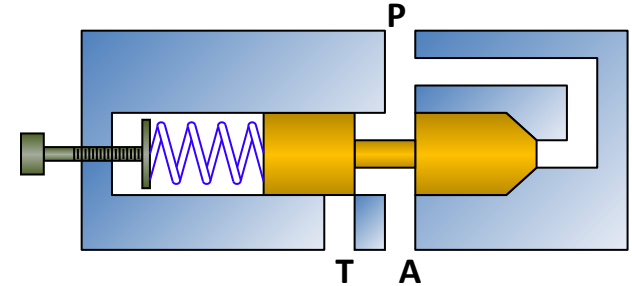
Example 3

- A pressure relief valve with a poppet area of 650 mm^2 and a spring constant of 450 kN/m has its spring initially compressed by 5 mm . The poppet must move by 2.5 mm from its fully closed position in order to pass full pump flow through the valve.
 - Determine the cracking pressure of the valve.
 - Determine the pressure of the valve needed for full pump flow through the valve



Example 3 Solution

- A pressure relief valve with a poppet area of 650 mm² and a spring constant of 450 kN/m has its spring is initially compressed by 5 mm. The poppet must move by 2.5 mm from its fully closed position in order to pass full pump flow through the valve.



At cracking pressure, fluid force balances initial spring compression.

$$\Sigma F = 0$$

$$F_{fluid} - F_{spring} = 0$$

$$p_{cracking} A_{poppet} = k_{spring} \delta_{initial}$$

$$p_{cracking} (650 \times 10^{-6}) = 450 \times 10^3 \times 5 \times 10^{-3}$$

$$p_{cracking} = 3.46 \times 10^6 \text{ Pa} = 3.46 \text{ MPa}$$

At full pump flow pressure, fluid force balances the total spring compression.

$$\Sigma F = 0$$

$$F_{fluid} - F_{spring} = 0$$

$$p_{fullflow} A_{poppet} = k_{spring} \delta_{total}$$

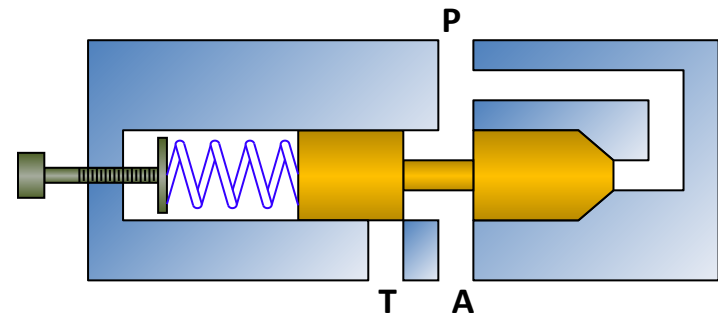
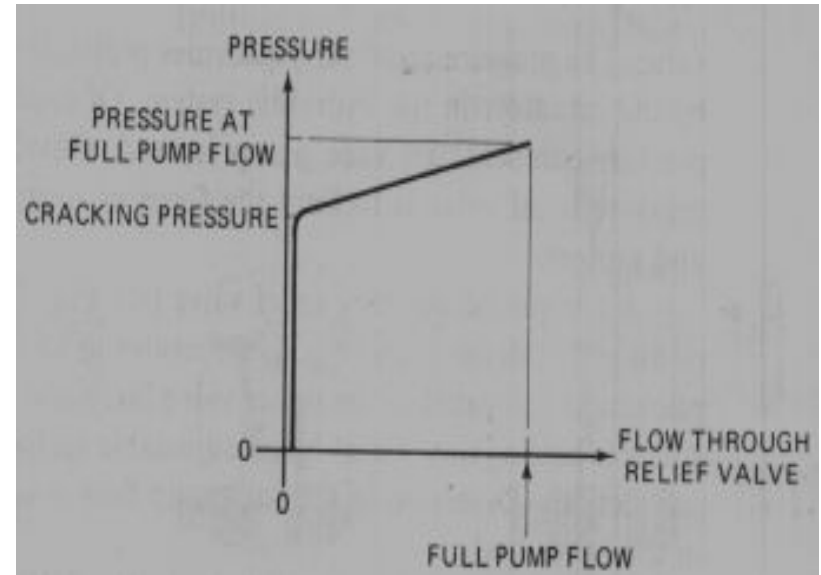
$$p_{fullflow} (650 \times 10^{-6}) = 450 \times 10^3 \times 7.5 \times 10^{-3}$$

$$p_{fullflow} = 5.19 \times 10^6 \text{ Pa} = 5.19 \text{ MPa}$$

The full pump flow pressure is 50% higher than the cracking pressure

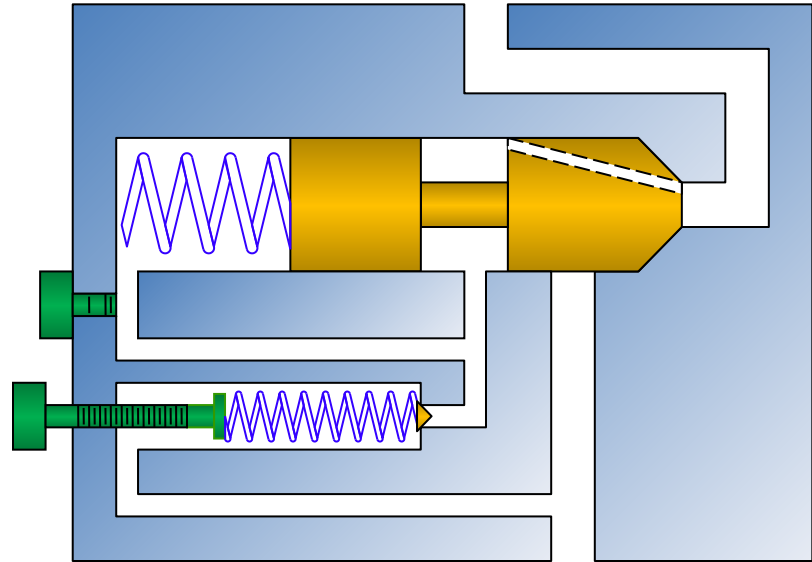
Compound (Pilot) Pressure Relief Valves

- The pressure override caused by the spring in a direct acting relief valve may result in a considerable power loss owing to the fluid being lost unnecessarily at a pressure between the cracking pressure and the full opening pressure.
- This happens when the inlet area of the valve is enlarged to accommodate high flow rates. A large inlet area calls for a stronger spring to balance fluid forces when the valve is closed, which, in turn, leads to high spring force when the spring deflects, and a large pressure override.



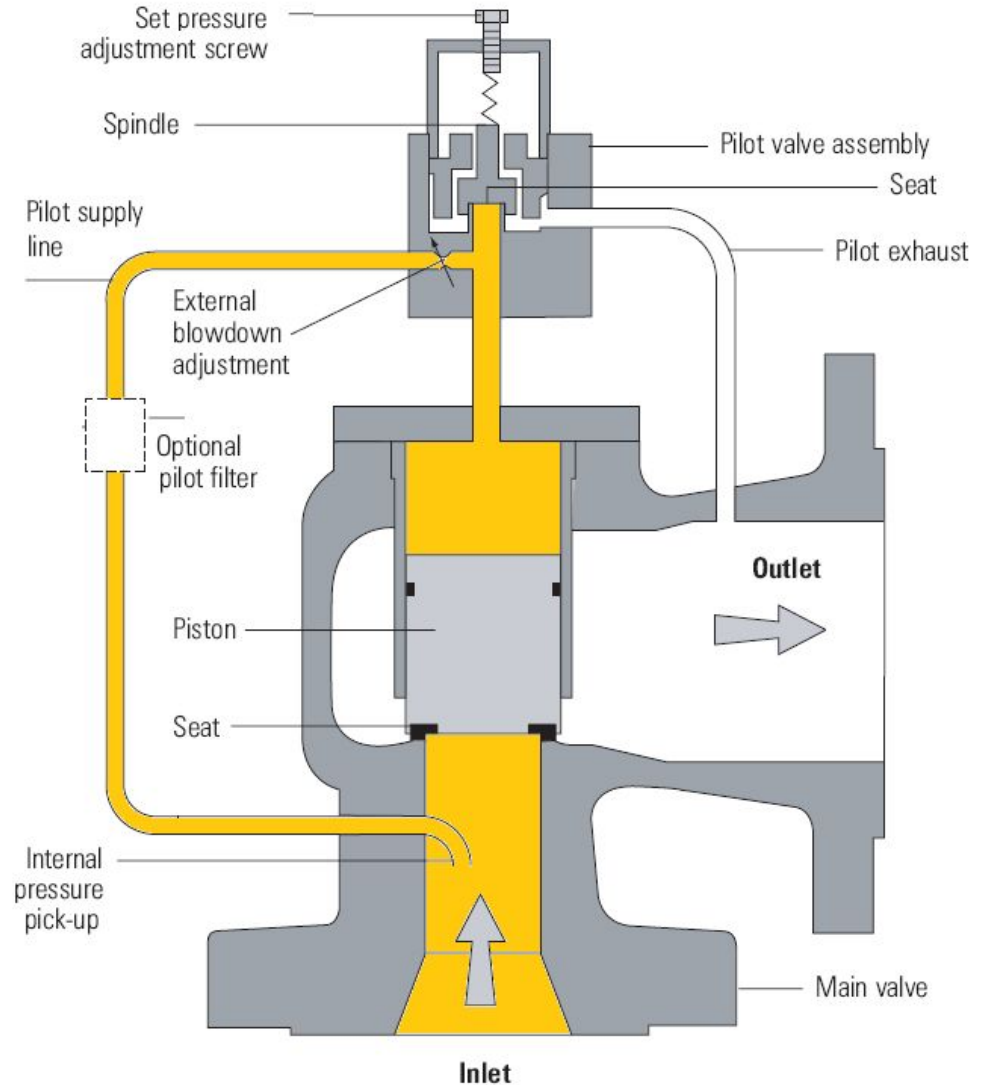
Compound (Pilot) Pressure Relief Valves

- A compound pressure relief valve uses the flow medium itself to apply the closing force on the valve disc through a pilot supply line assembly.
- The exposed bottom area of the disc is less than the top area. As both ends are exposed to the same pressure, the closing force, resulting from the larger top area, is greater than the inlet force. The resultant downward force therefore holds the piston firmly on its seat.



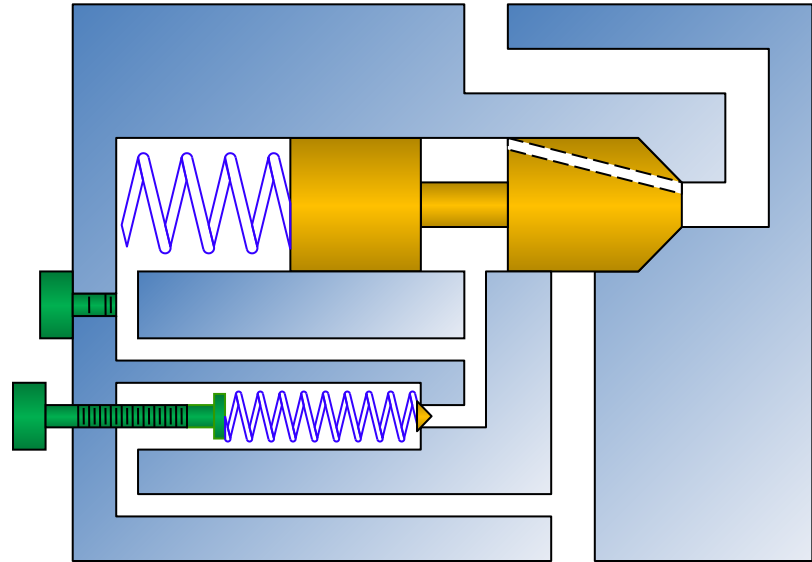
Compound (Pilot) Pressure Relief Valves

- A pilot valve, which is itself a small direct pressure relief valve is used to sense the fluid pressure. When the inlet pressure reaches the set pressure, the pilot valve will pop open, releasing the fluid pressure above the disc.
- With much less fluid pressure acting on the upper surface of the piston, the inlet pressure generates a net upwards force and the piston will leave its seat. This causes the disc to pop open quickly with little pressure override, diverting the full flow of the pump to the tank.



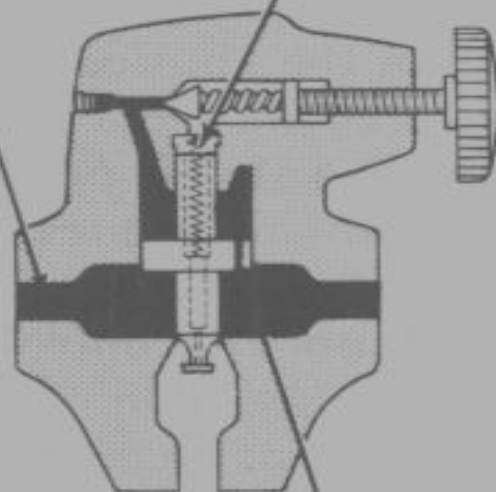
Compound (Pilot) Pressure Relief Valves

- When the inlet pressure has been sufficiently reduced, the pilot valve will reclose, preventing the further release of fluid from the top of the piston, thereby re-establishing the net downward force, and causing the piston to reseat.



1. INLET PRESSURE
HERE...

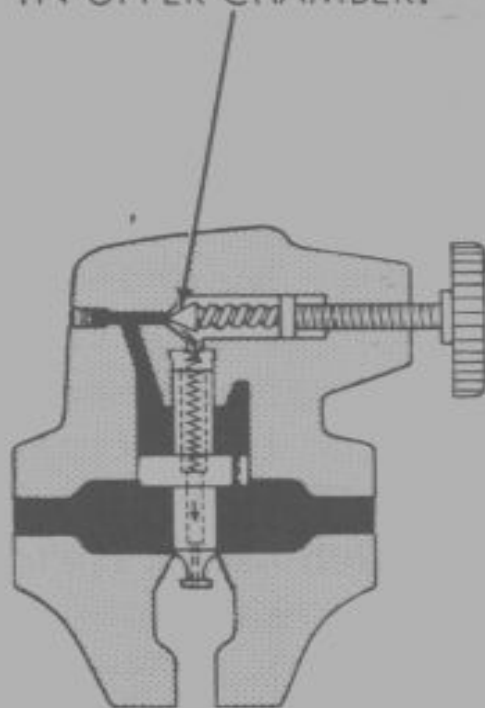
3. SPRING HOLDS
PISTON CLOSED.



2. IS SENSED ABOVE
PISTON AND AT PILOT
VALVE THROUGH
ORIFICE IN PISTON.

VIEW A
CLOSED

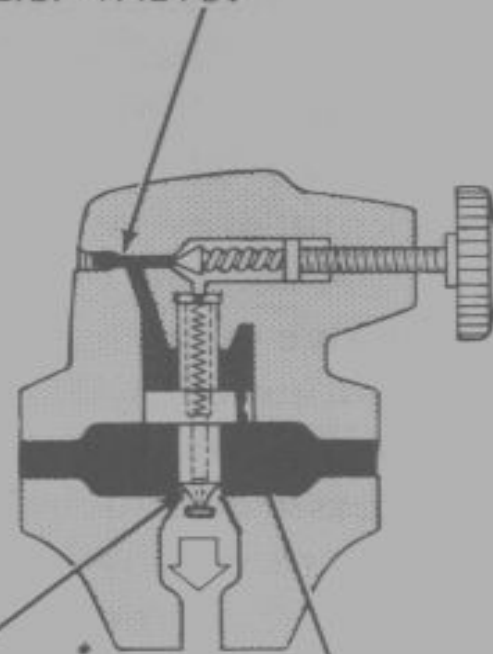
4. WHEN THE VALVE
SETTING IS REACHED,
THE POPPET "OPENS"
LIMITING PRESSURE
IN UPPER CHAMBER.



6. PISTON MOVES UP TO
DIVERT PUMP OUTPUT
DIRECTLY TO TANK.

VIEW B
CRACKED

7. VENT CONNECTION
PERMITS UNLOADING
PUMP THROUGH
RELIEF VALVE.



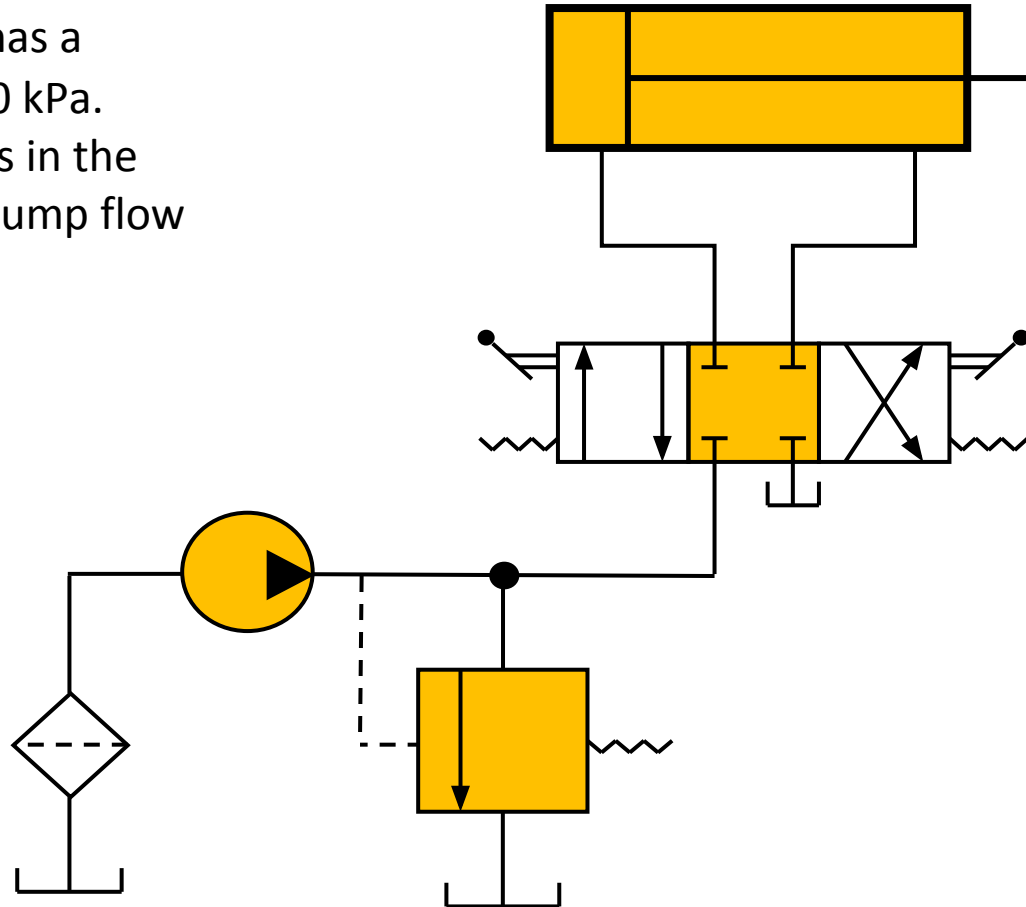
5. WHEN THIS
PRESSURE IS 20 psi
HIGHER THAN IN
UPPER CHAMBER ...

VIEW C
RELIEVING

Example 4:

Power loss in Pressure Relief Valves

- A pressure relief valve has a pressure setting of 7000 kPa. Calculate the power loss in the valve if it admits a full pump flow of $1.26 \times 10^{-3} \text{ m}^3/\text{s}$.

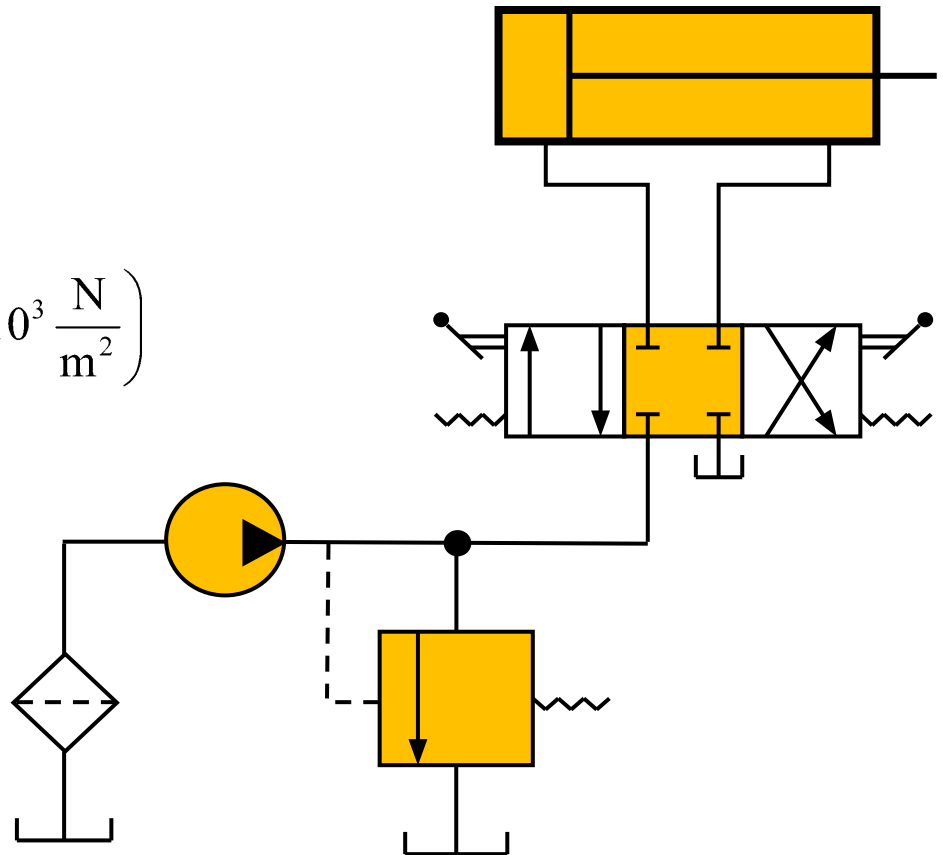


Example 4:

Power loss in Pressure Relief Valves

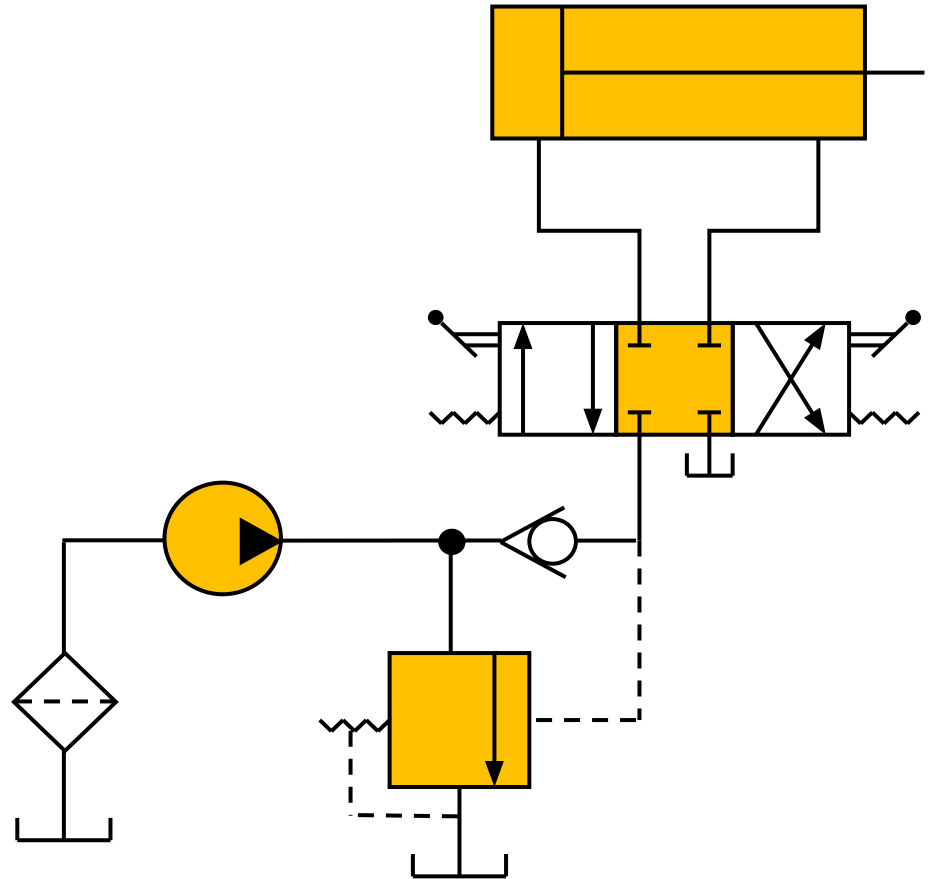
- A pressure relief valve has a pressure setting of 7000 kPa. Calculate the power loss in the valve if it admits a full pump flow of $1.26 \times 10^{-3} \text{ m}^3/\text{s}$.

$$P = Q\Delta p = \left(1.26 \times 10^{-3} \frac{\text{m}^3}{\text{s}}\right) \times \left(7000 \times 10^3 \frac{\text{N}}{\text{m}^2}\right)$$
$$= 8820 \text{ W} = 8.82 \text{ kW}$$



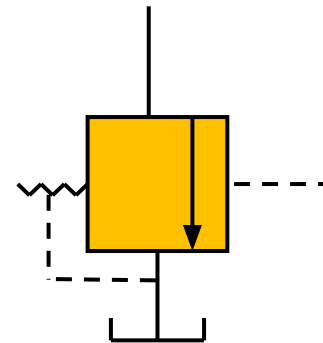
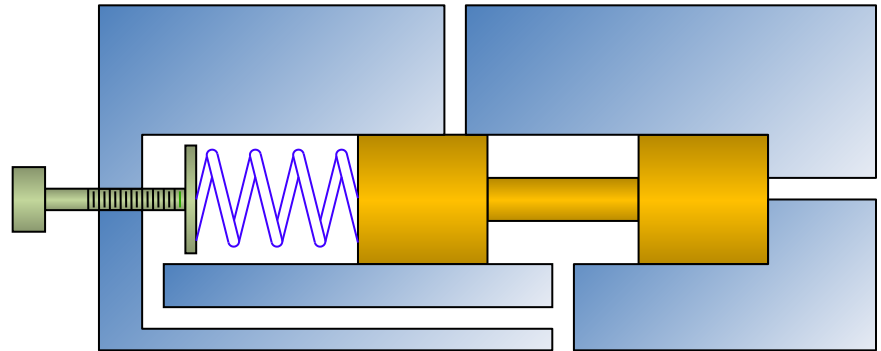
Unloading Valves

- An unloading valve is a pressure control valve that operates in a manner somewhat similar to a pilot pressure relief valve.
- In contrast to a piloted pressure relief valve, which responds to pressure in the circuit just upstream the valve, an unloading valve responds to a pilot pressure coming from a remote source.



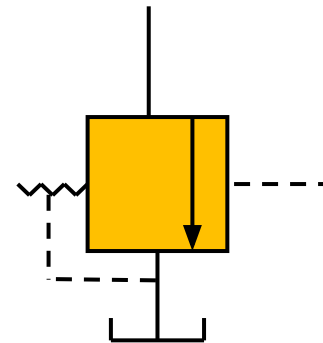
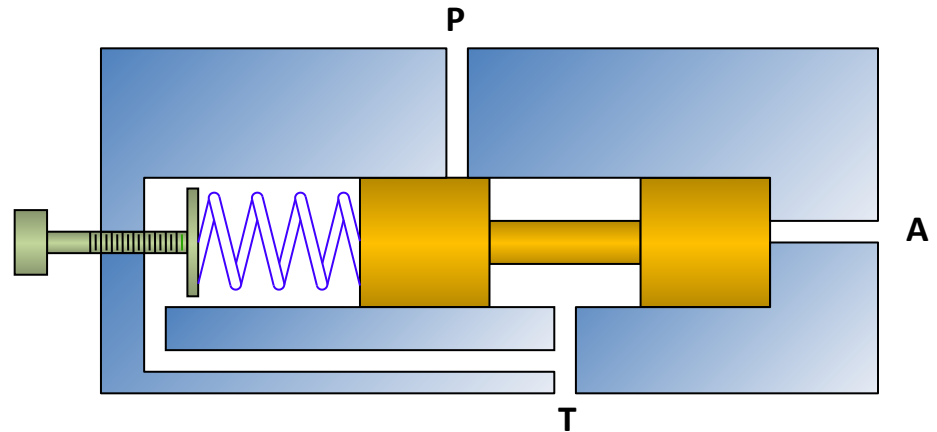
Unloading Valves

- An unloading valve permits a pump to build pressure to an adjustable pressure setting, and then allows it to discharge to the tank at essentially zero pressure as long as pilot pressure is maintained from the remote source.
- With the unloading valve, the pump has essentially no load and is developing a minimum amount of power. With a pressure relief valve, the pump is delivering full pump flow at the pressure relief valve setting, and is thus operating at maximum power conditions.



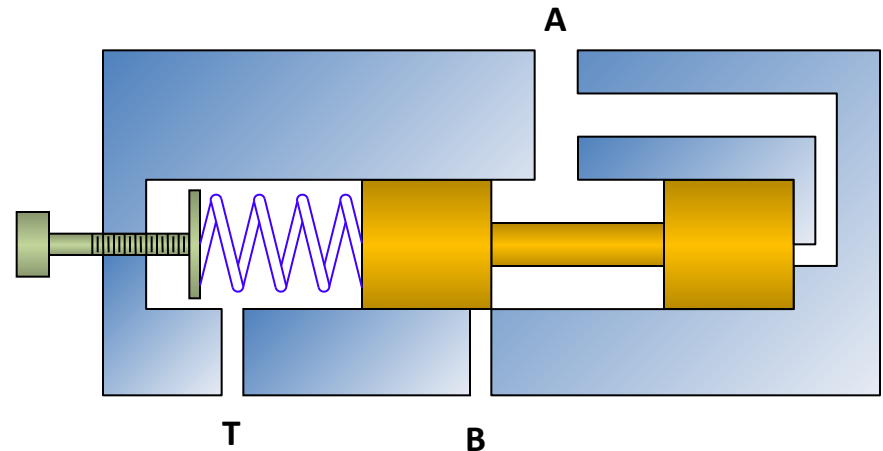
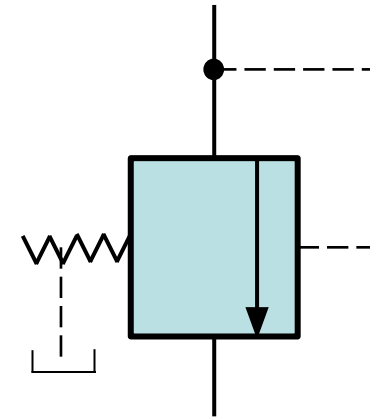
Unloading Valves

- Note that the chamber containing the spring is ported to the discharge side of the valve which will be normally be connected to the tank. This is necessary so that the small leakage past the spool into this chamber due to inlet pressure will not build up in the spring chamber, and hence prevent the valve from opening.
- This valve is said to be internally drained because the path from the spring chamber to the discharge side of the valve lies inside the valve itself. Note the symbol for the unloading valve.



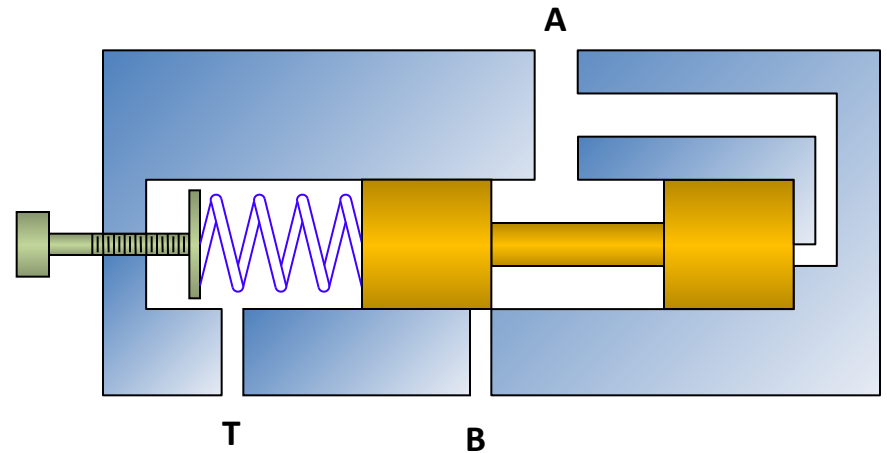
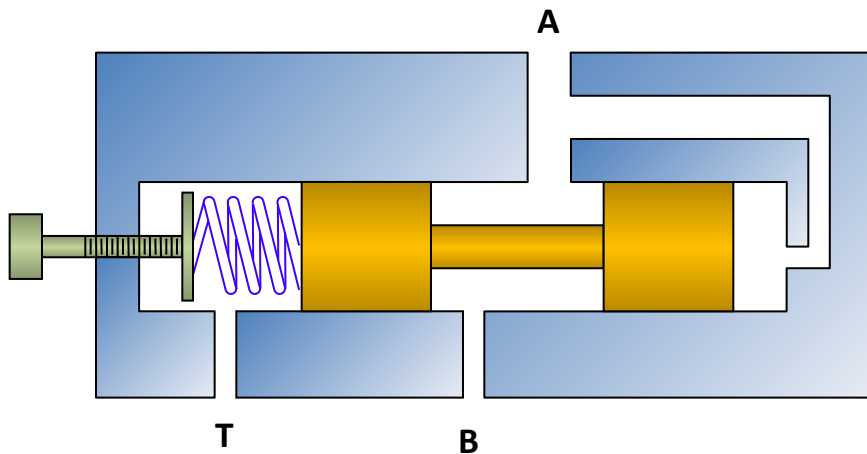
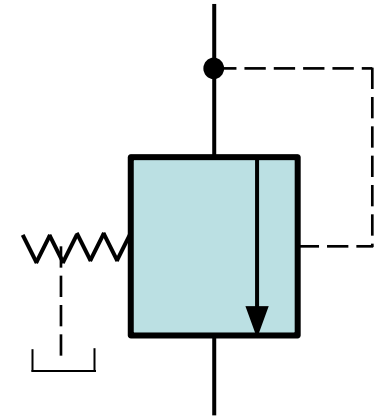
Sequence Valve

- A sequence valve is a valve of the pressure relief type in which the vented fluid is ported to a working portion of the circuit, instead of returning to the reservoir, or tank.
- The circuit from which the fluid is ported is called the primary circuit, and the circuit to which the fluid is ported is called the secondary circuit. A primary circuit pressure is used to actuate the sequence valve. After the valve sequences, this primary pressure is maintained at the valve secondary port.



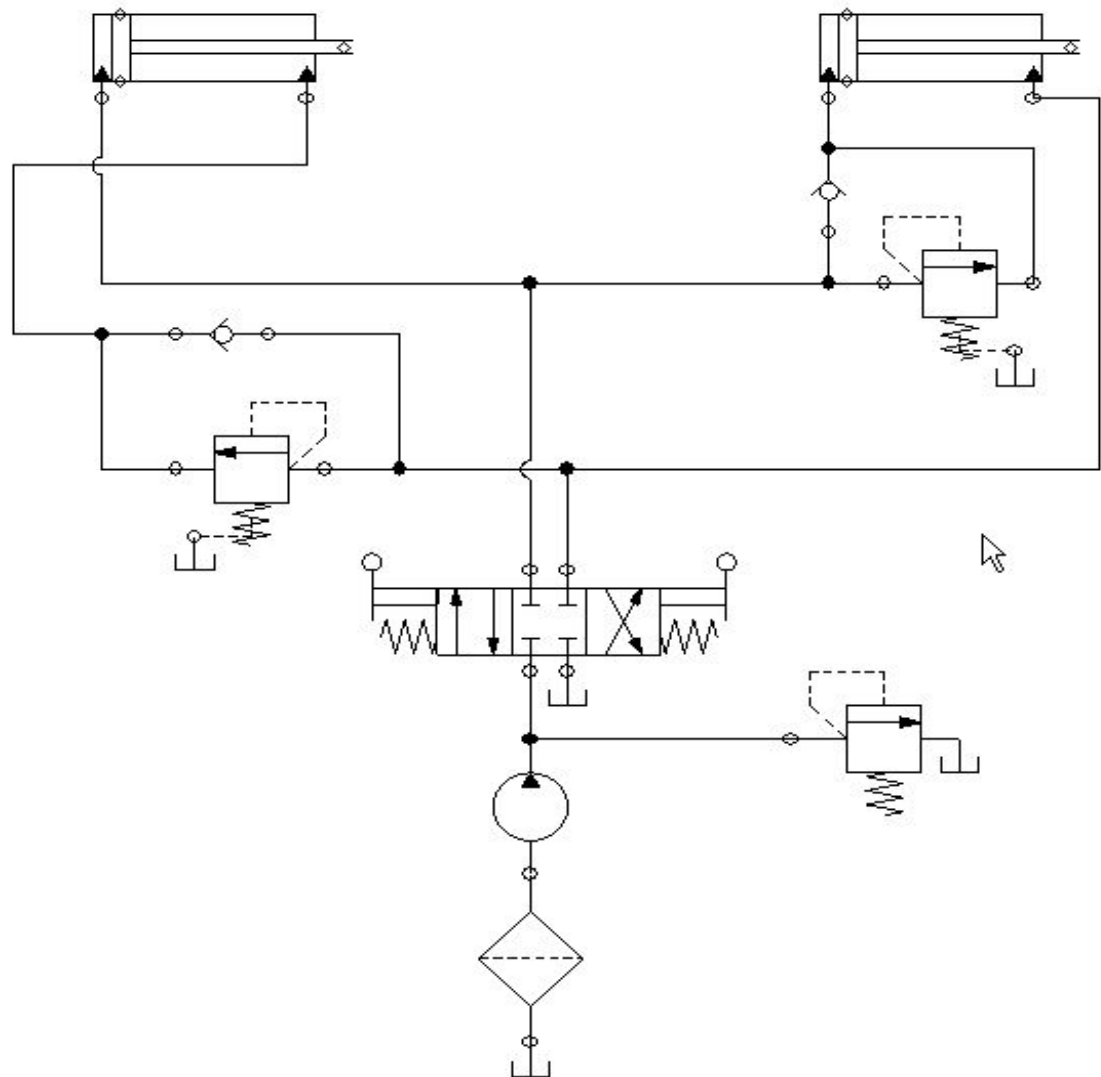
Sequence Valve

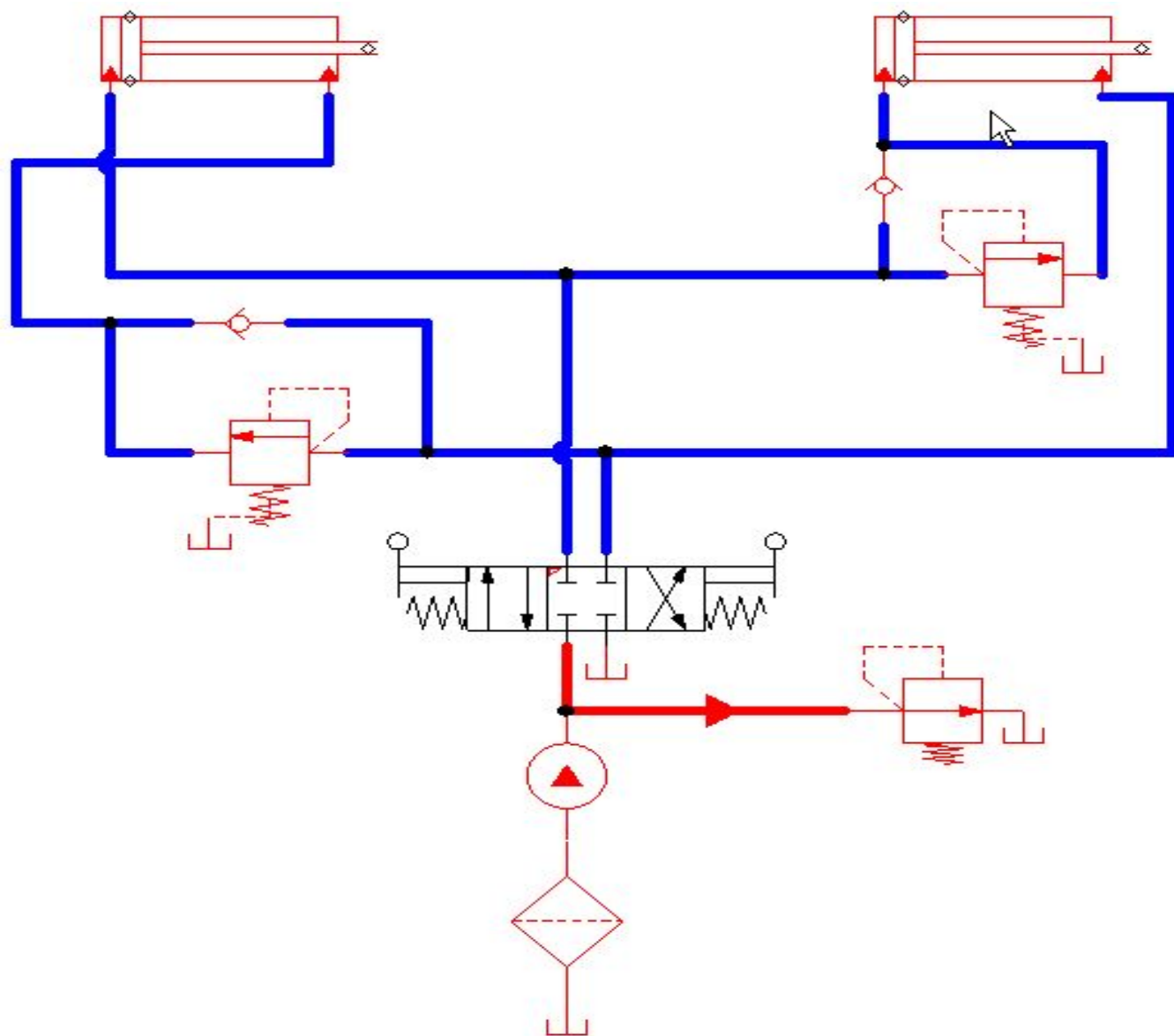
- Note that the spring chamber of the sequence valve must be drained to prevent the build up of pressure caused by leakage past the spool from the pressure at the primary port. This drain is connected by a an external line to the reservoir.

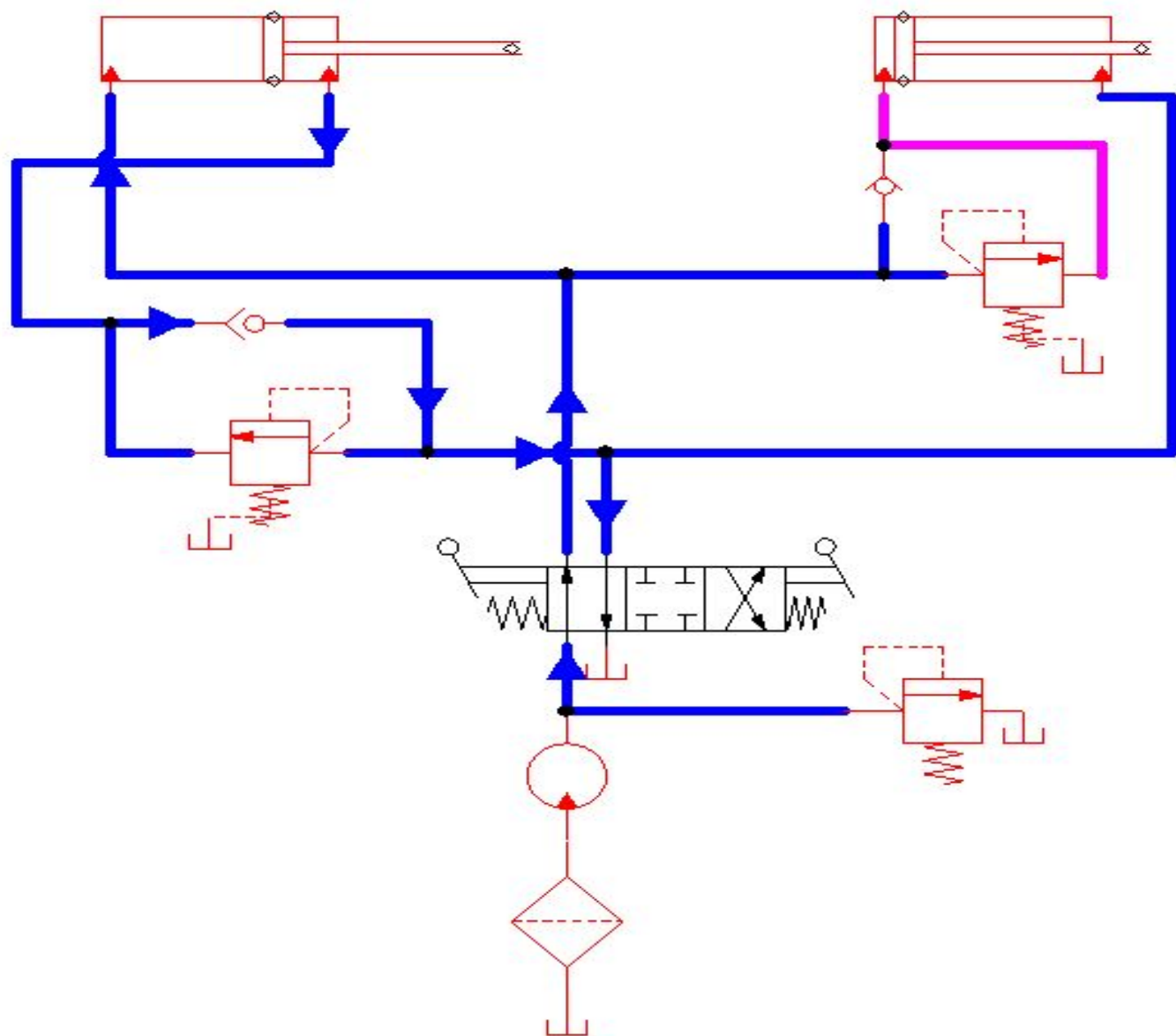


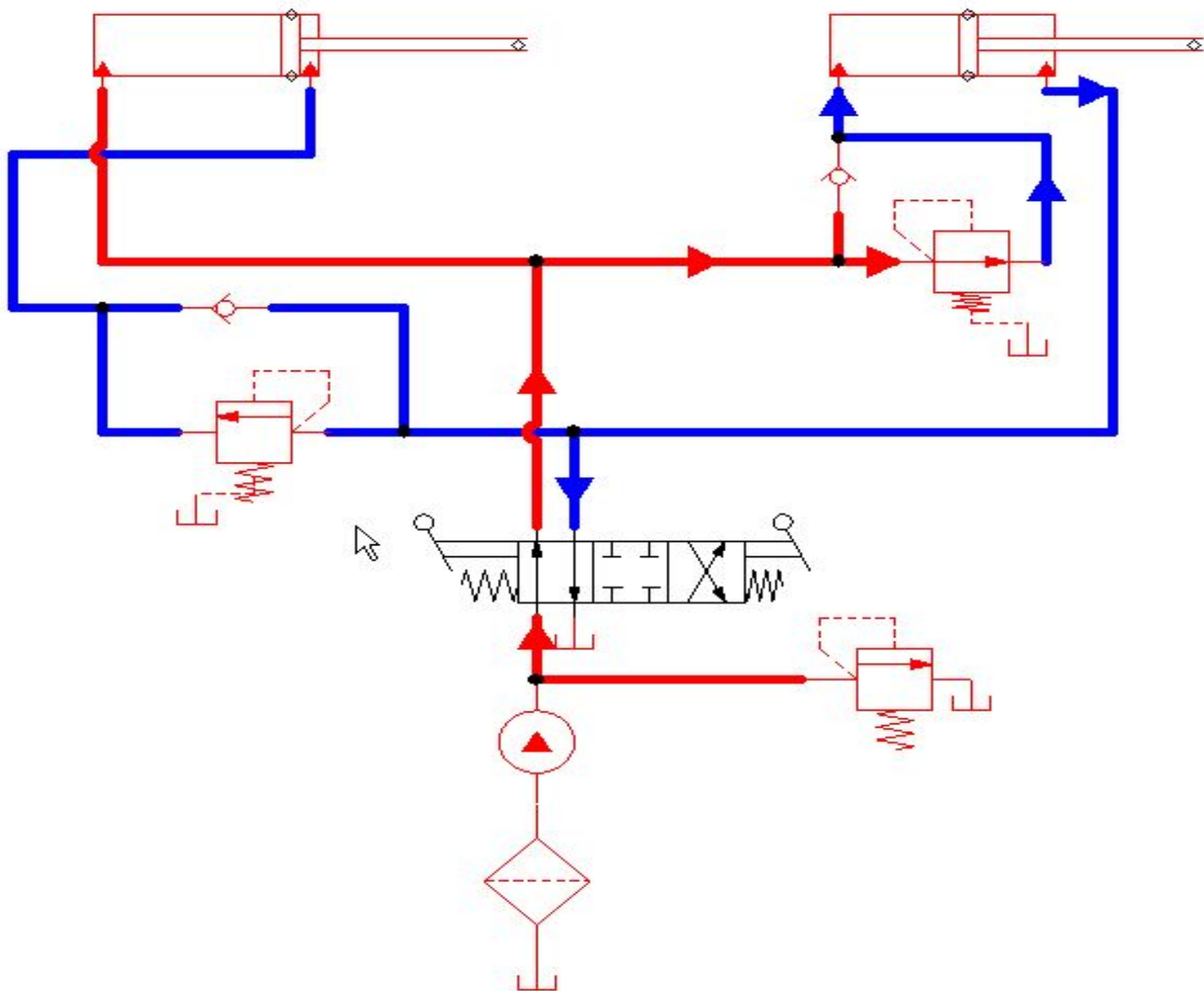
Sequence Valve

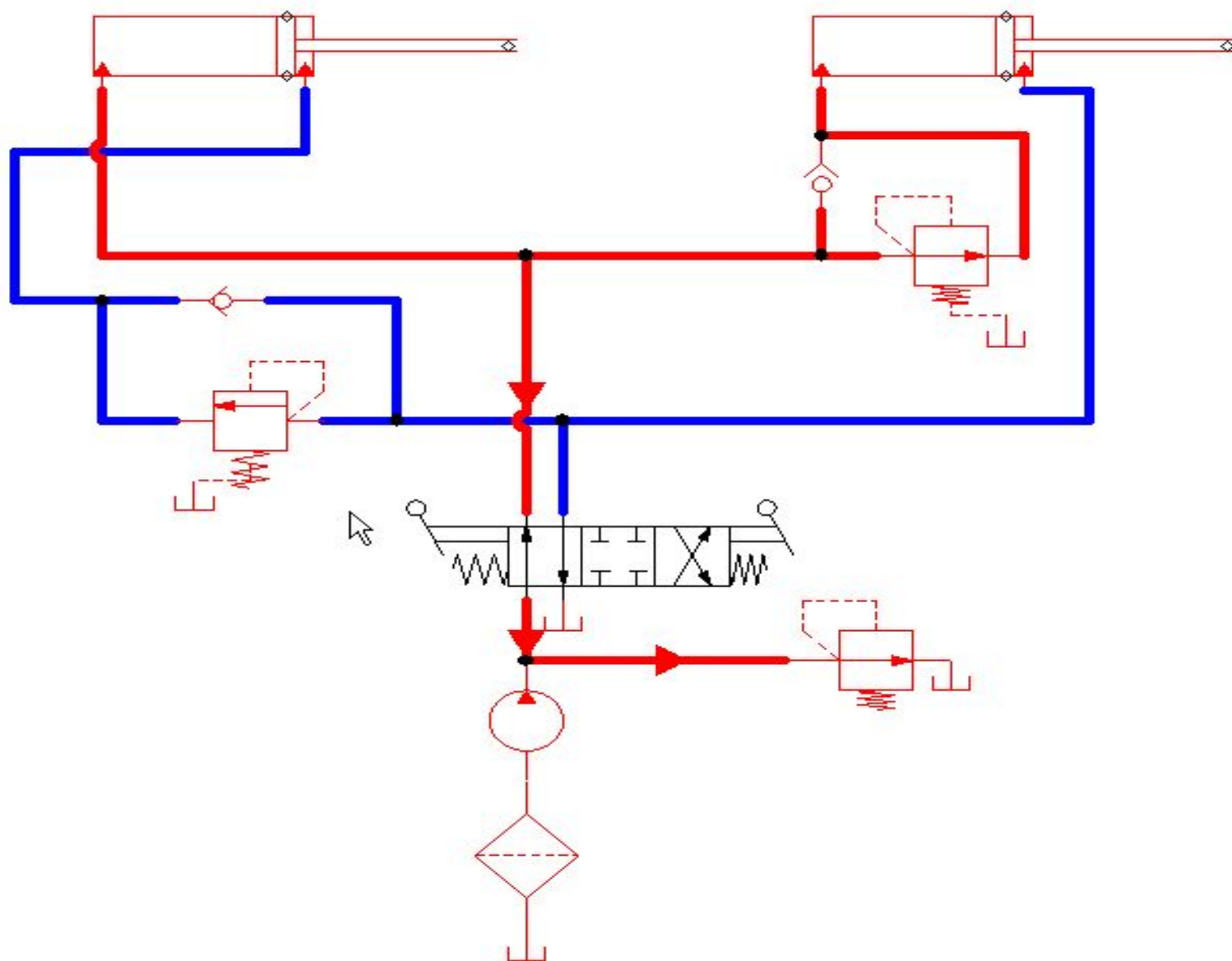
- Sequence valves are used to direct fluid in a sequential manner. A typical application is to control the sequence in which two actuators are to operate.

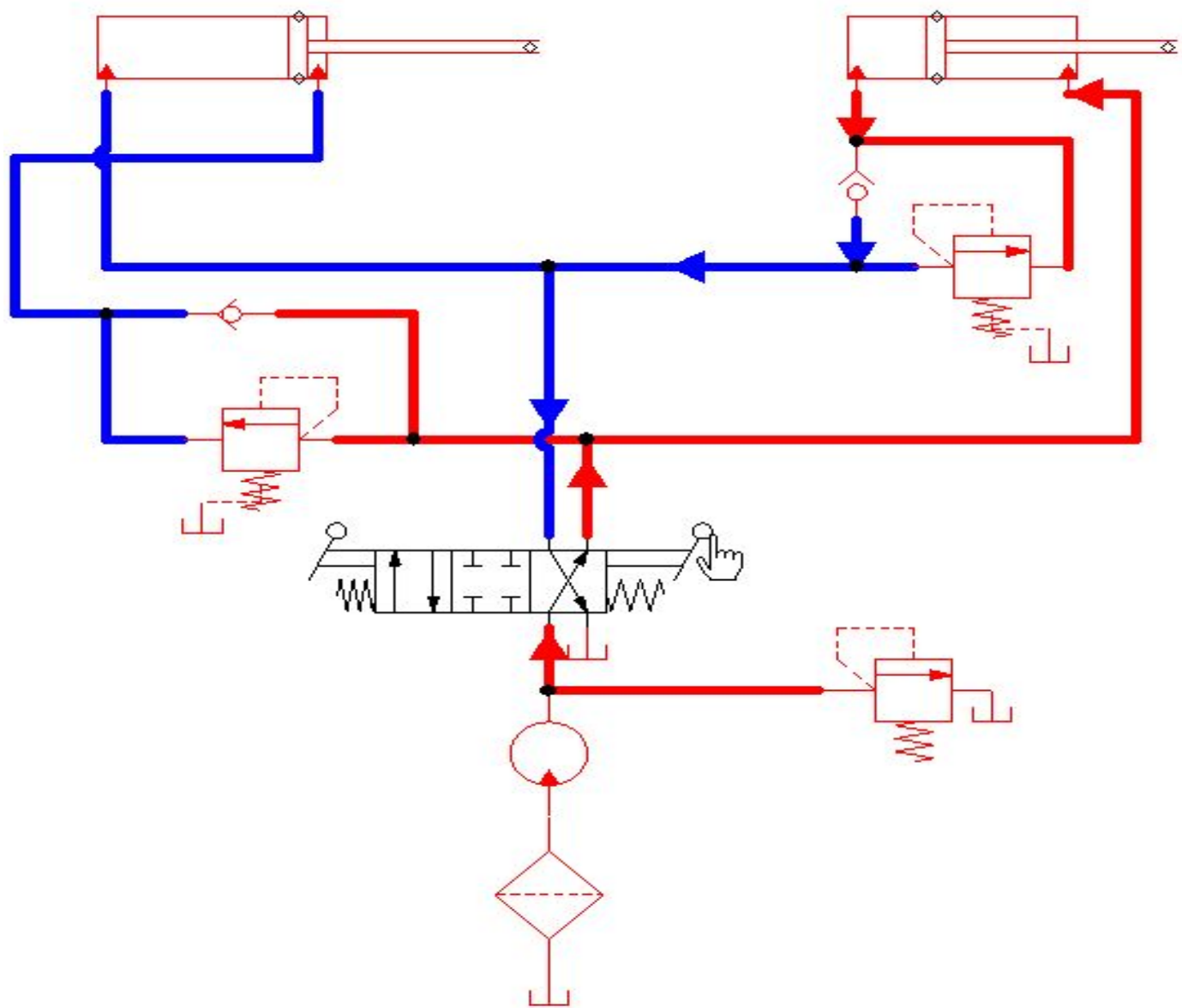


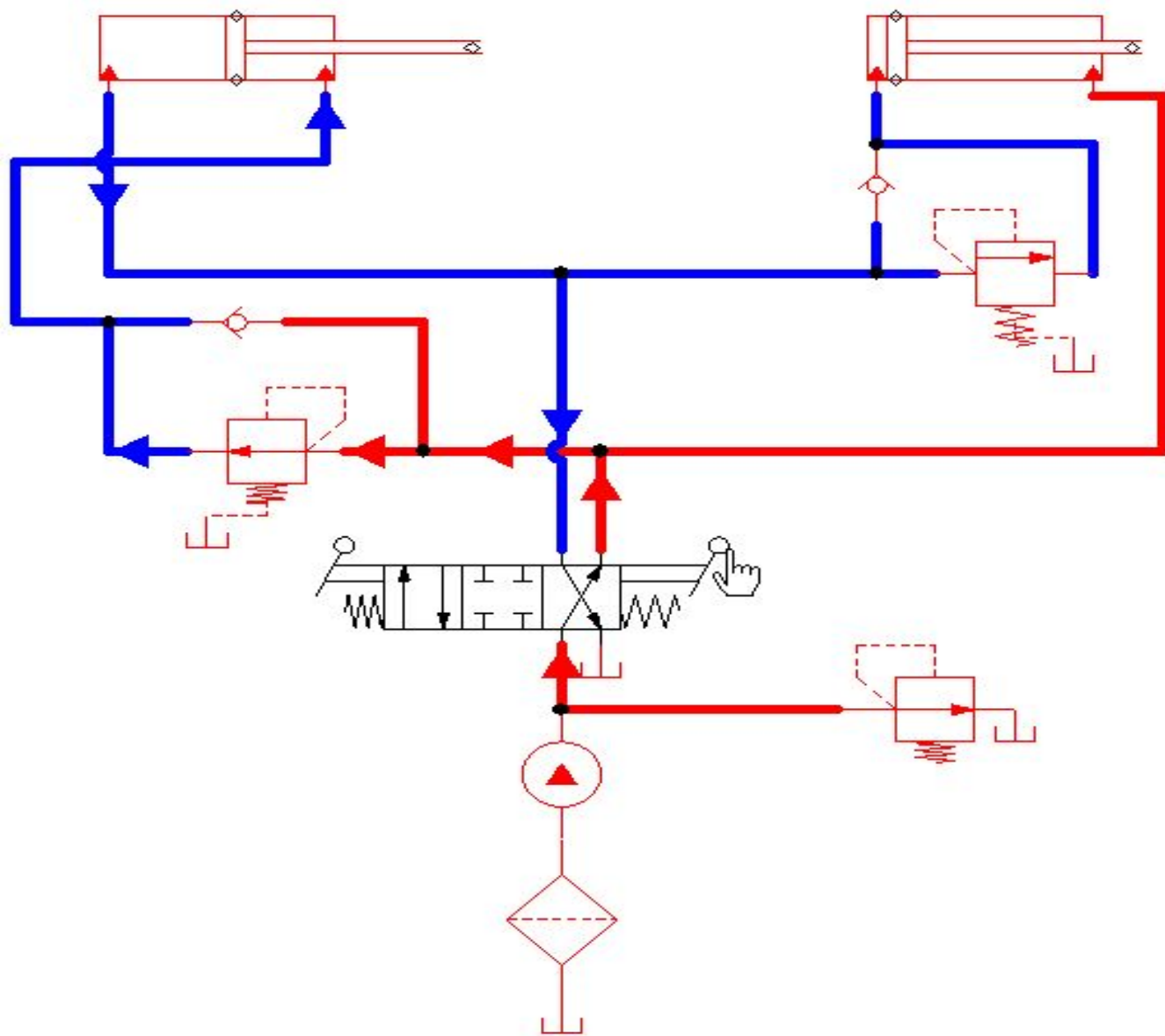


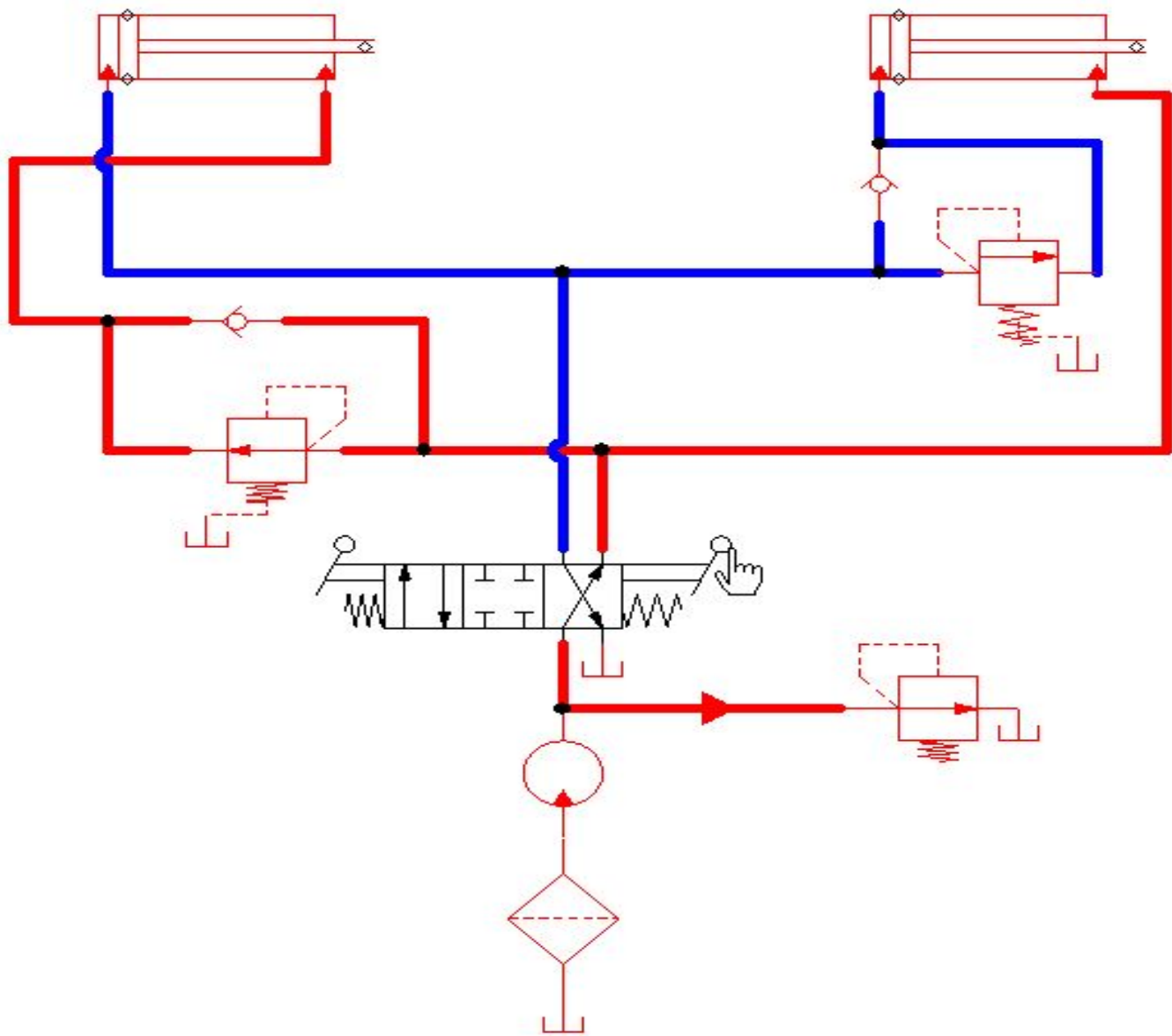






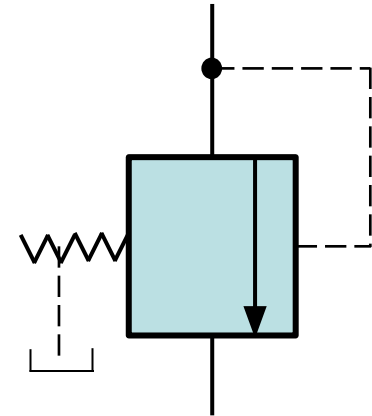






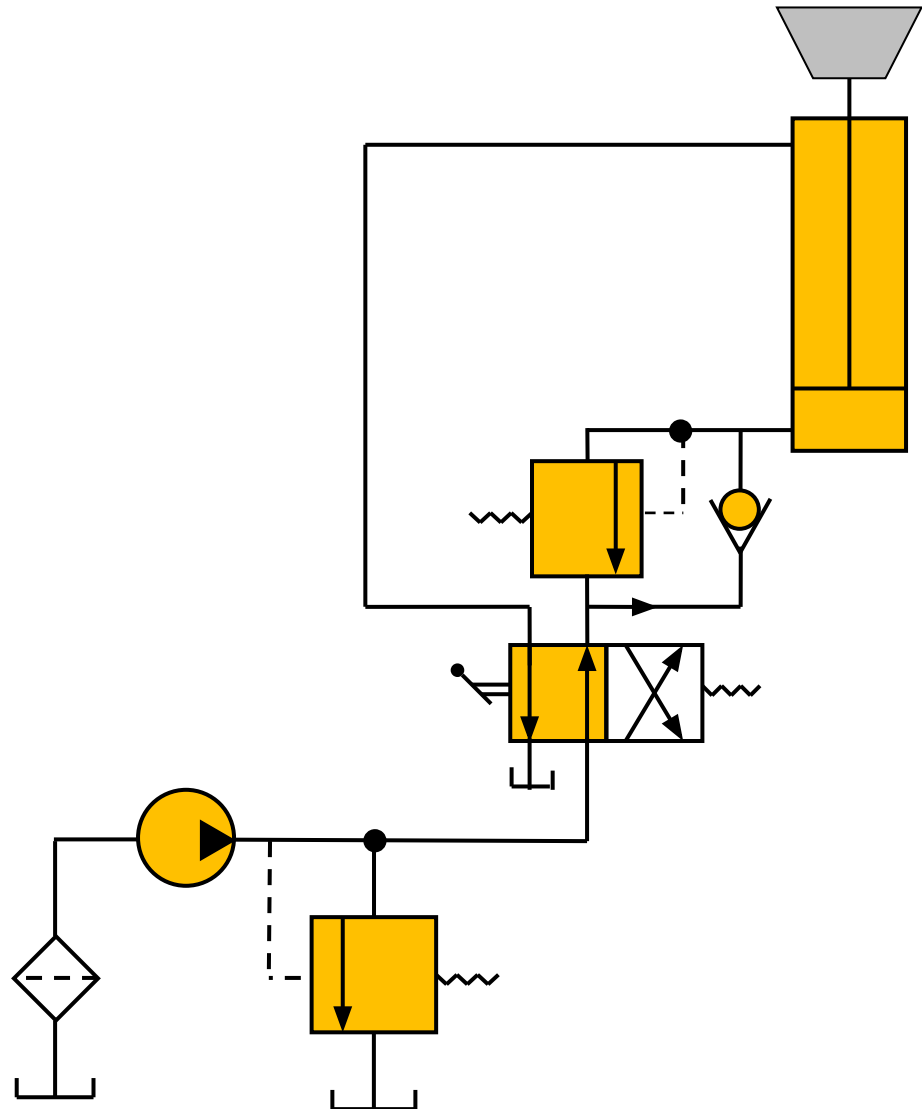
Counterbalance Valve

- A counterbalance valve permits free flow in one direction, and a restricted flow in the opposite direction. It is commonly used in conjunction with a single acting cylinder that elevates and lowers a load.
- When the pump is off, the counterbalance valve prevents the load from falling under gravity



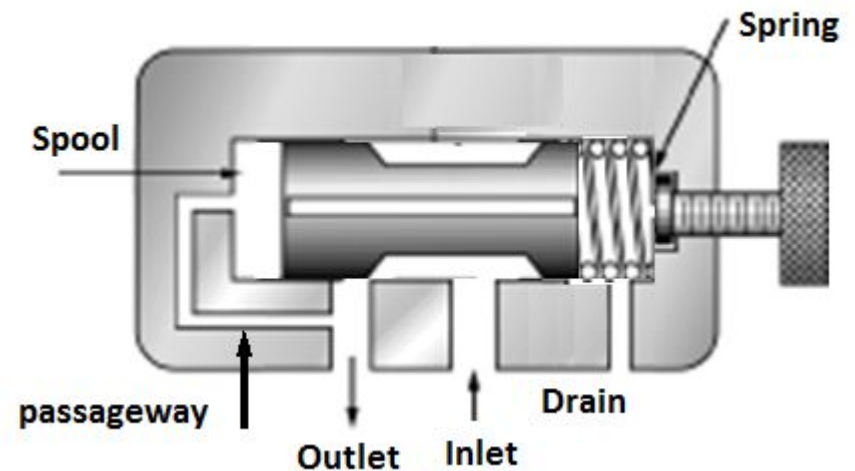
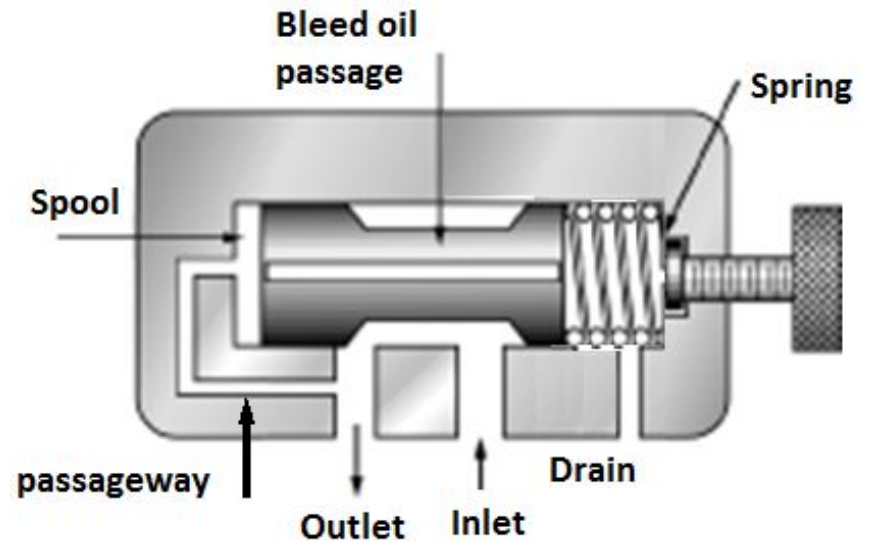
Counterbalance Valve

- When the pump is off, the counterbalance valve prevents the load from falling under gravity by maintaining a back pressure against the load. When the pump is on, fluid flows through the check valve, which offers little resistance to flow, and the load can be elevated.
- When the DCV is moved to the right envelope, the counterbalance valve opens, but offers a resistance to flow that is adjustable by the spring setting. This prevents the load from falling rapidly.



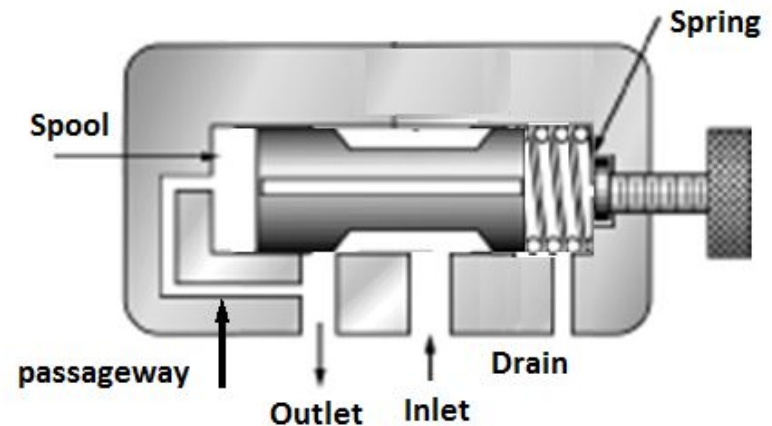
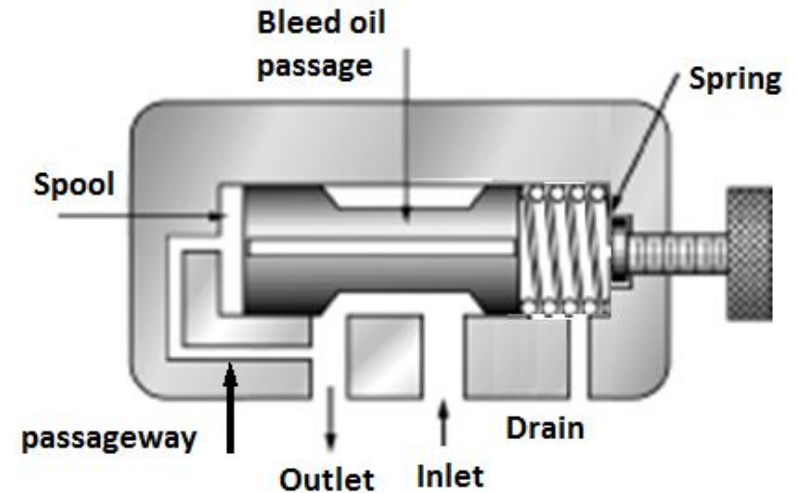
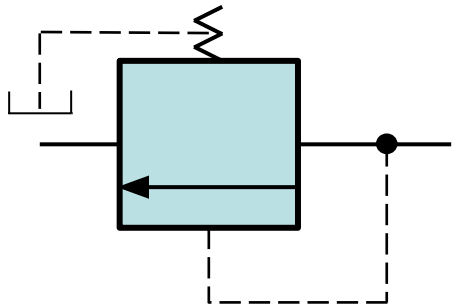
Pressure Reducing Valves

- A pressure reducing valve is used to maintain reduced pressures in specified locations of hydraulic systems.
- A spring loaded spool is used to control the outlet pressure. If the pressure at the outlet is below the spring setting, the spool moves to the left, allowing free flow from the inlet to the outlet.
- The internal passageway transmits outlet oil pressure to the spool end opposite the spring. As the outlet pressure increases, the spool moves to the right to partially block the outlet port, until the force from the oil pressure at the outlet balances the spring force.



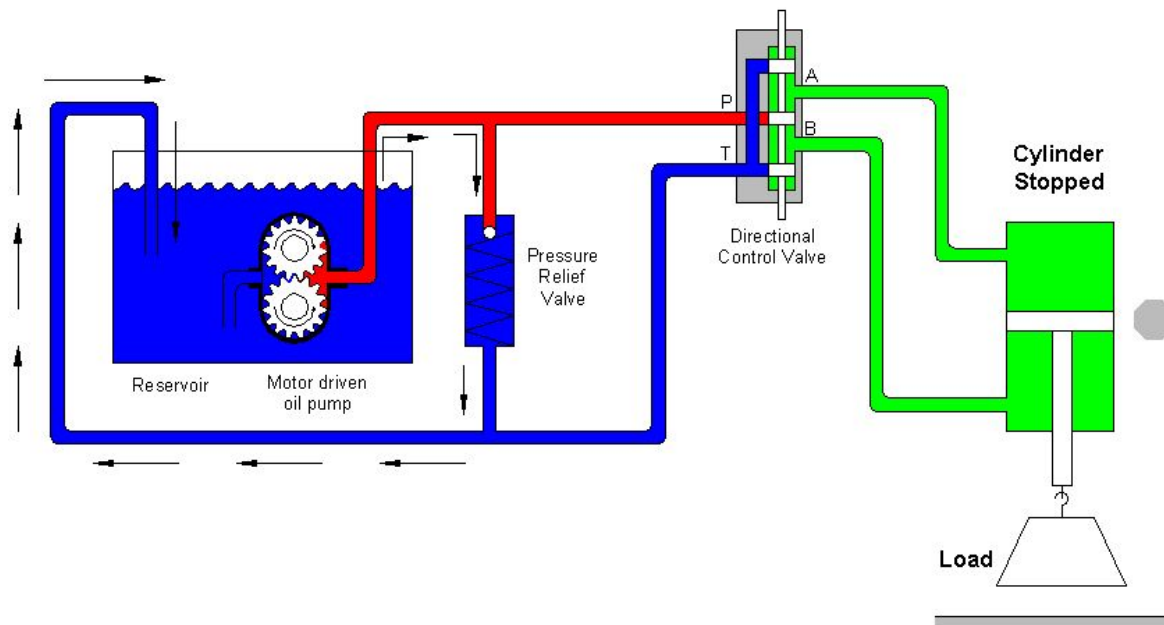
Pressure Reducing Valves

- If the valve closes completely, leakage past the spool could cause downstream pressure to build up above the valve setting.
- Pressure build up is prevented because a continuous bleed is permitted via a separate drain line connected to the tank



Sizing Pressure Relief Valves

- The size of a pressure relief valve should be specified such that when it opens, it relieves a sufficient amount of fluid without causing the pressure in the protected system to exceed a specified limit.
- In the system below, for example, when the pressure relief valve opens it should allow the flow discharged by the pump to flow back to the tank without causing the pressure downstream the pump to exceed the safety limits of the system.



Sizing of Pressure Relief Valves

- The size of a pressure relief valve is thus determined by the flow rate, Q , the valve needs to pass when it is fully open, when a certain pressure difference, Δp is applied across it.
- Recall that for straight pipe flow, Q and Δp are related by as follows:

$$\Delta P = f \left(\frac{L}{D} \right) \left(\frac{\rho v^2}{2} \right) = f \left(\frac{L}{D} \right) \left(\frac{\rho v^2}{2} \right) \frac{A^2}{A^2} = \frac{8f}{\pi^2} \frac{L}{D^5} \rho Q^2$$

Turbulent Flow

$$f = F(\varepsilon/D)$$

$$\Delta P = \frac{8f}{\pi^2} \frac{L}{D^5} \rho Q^2$$

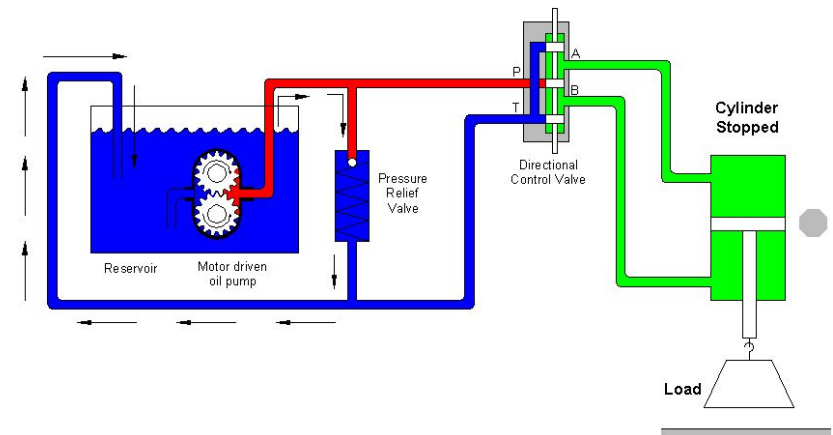
$$Q = \sqrt{\frac{\pi^2 D^5}{8fL}} \sqrt{\frac{\Delta P}{\rho}} = C_{trb} \sqrt{\frac{\Delta P}{\rho}}$$

Laminar Flow

$$f = \frac{64}{Re} = \frac{64\mu}{\rho v D}$$

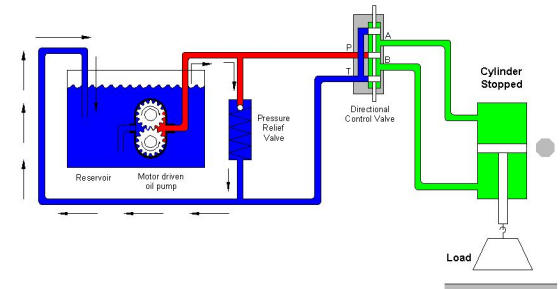
$$\Delta P = \frac{64\mu}{\rho v D} \frac{L}{2A^2 D} \rho Q^2 = \frac{32L}{D^2 A} \mu Q = \frac{128L}{\pi D^4} \mu Q$$

$$Q = \frac{\pi D^4}{128L} \Delta P = C_{lam} \frac{\Delta P}{\mu}$$



Sizing of Pressure Relief Valves

- The coefficients C_{lam} and C_{trb} are functions of pipe geometry only and they are called the laminar and turbulent pipe flow coefficients, respectively
- Similar flow coefficients may be defined for pressure relief valves. These coefficients are determined experimentally by valve manufacturers for a certain pressure relief valve, and they determine the amount of flow the valve will pass at a certain pressure difference when it is fully open.

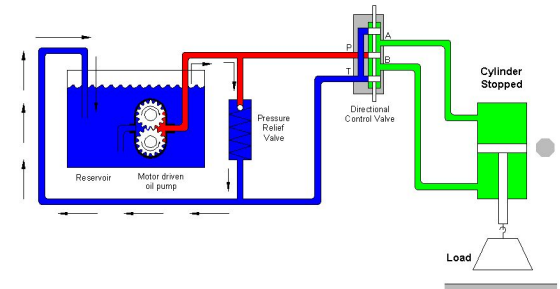


$$Q_{lam} = C_{lam} \frac{\Delta P}{\mu}, C_{lam} = \frac{\pi D^4}{32L}$$

$$Q_{trb} = C_{trb} \sqrt{\frac{\Delta P}{\rho}}, C_{trb} = \sqrt{\frac{\pi^2 D^5}{8fL}}, f = F(\varepsilon/D)$$

Sizing of Pressure Relief Valves

- Pipe flow coefficients are both inversely proportional to the length of the pipe. The 'equivalent length' method is sometimes used as an alternative in specifying the size of a pressure relief valve. The equivalent length for a pressure relief valve is specified for a pipe at a certain diameter.
- A valve will pass a flow equal to that pipe of that diameter at equivalent length.

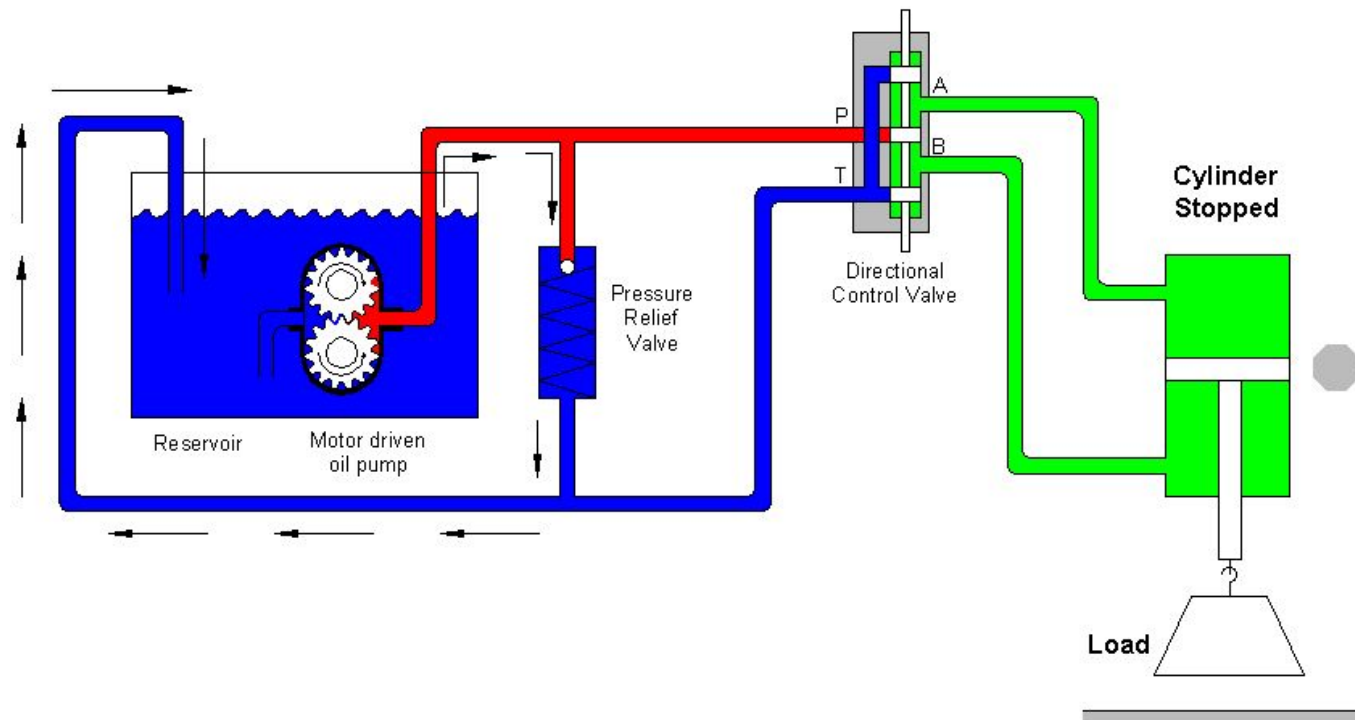


$$Q_{lam} = C_{lam} \frac{\Delta P}{\mu}, C_{lam} = \frac{\pi D^4}{32L}$$

$$Q_{trb} = C_{trb} \sqrt{\frac{\Delta P}{\rho}}, C_{trb} = \sqrt{\frac{\pi^2 D^5}{8fL}}, f = F(\epsilon/D)$$

Example

- Calculate the minimum values of flow coefficients for the pressure relief valve for the circuit of HW2 for the case of load speed, $v_l = v_c$ and $v_l = 2v_c$, where v_c is the maximum load speed at which laminar flow conditions are maintained in the piping



Solution

- Recall that $v_c = 3.64$ m/s and the pressure at the pump outlet during load lifting at $v_l = v_c$ was found to be 11215 kPa with a flow rate $Q = 2.55 \times 10^{-3}$ m³/s. The pressure at point B upstream the valve during load lifting is then:

$$P_B = P_{pump} - \frac{32\mu L_{AB} v_{p-r}}{D^2} = 11215 \times 10^3 - \frac{32 \times 0.1 \times 10 \times 5.19}{(25 \times 10^{-3})^2} = 10950 \text{ kPa}$$

- The cracking pressure of the valve may then be set to be $1.2 \times P_B$. However, according to the stiffness of the valve's spring, it may not open fully until the pressure reaches 1.5 times the cracking pressure.

$$P_{fo} = 1.2 \times 1.5 \times P_B = 1.8 \times 10950 = 19710 \text{ kPa}$$

- The valve flow coefficient and equivalent length are thus

$$C_{lam} = \frac{\mu Q_{lam}}{\Delta P} = \frac{0.1 \times 2.55 \times 10^{-3}}{19710 \times 10^3} = 1.3 \times 10^{-11} \text{ m}^3$$

$$L_{lam} = \frac{\pi D^4}{32 C_{lam}} = \frac{\pi (25 \times 10^{-3})^4}{32 \times 1.3 \times 10^{-11}} = 2964 \text{ m}$$

Solution

- For load speed $v_l = 2v_c$ the pressure at the pump outlet was found to be 13900 kPa with a flow rate $Q = 5.1 \times 10^{-3} \text{ m}^3/\text{s}$. The pressure at point B upstream the valve during load lifting is then:

$$P_B = P_{\text{pump}} - f \left(\frac{L_{AB}}{D_p} \right) \left(\frac{\rho v^2}{2} \right) = 13900 \times 10^3 - 0.06 \left(\frac{10}{25 \times 10^{-3}} \right) \left(\frac{900 \times 10.38^2}{2} \right) = 12736 \text{ kPa}$$

- The full open pressure is thus

$$P_{fo} = 1.2 \times 1.5 \times P_B = 1.8 \times 12736 = 22925 \text{ kPa}$$

- The valve flow coefficient and equivalent length are thus

$$Q_{trb} = C_{trb} \sqrt{\frac{\Delta P}{\rho}}, C_{trb} = \sqrt{\frac{\pi^2 D^5}{8 f L}} =$$

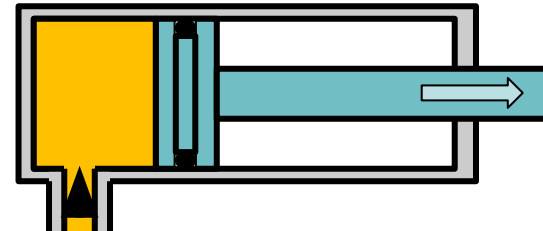
$$C_{trb} = \frac{Q_{trb}}{\sqrt{\Delta P / \rho}} = \frac{5.1 \times 10^{-3}}{\sqrt{22925 \times 10^3 / 900}} = 3.2 \times 10^{-5} \text{ m}^2$$

$$L_{trb} = \frac{\pi^2 D^5}{8 f C_{trb}^2} = \frac{\pi^2 (25 \times 10^{-3})^5}{8 \times 0.06 \times (3.2 \times 10^{-5})^2} = 196.6 \text{ m}$$

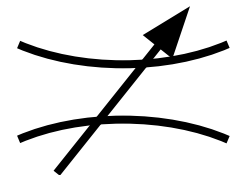
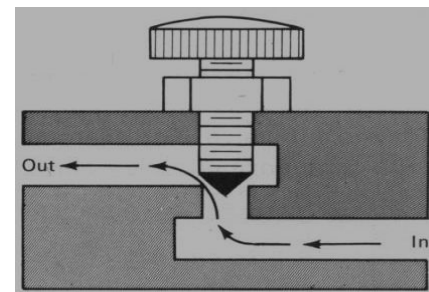
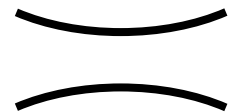
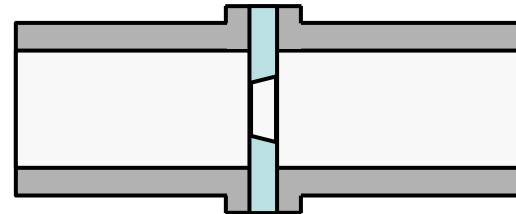
Flow Control Valves

Flow Control Valves

- Flow control valves are used to regulate the speed of hydraulic cylinders and motors by controlling the flow rate to these actuators. They may be as simple as a fixed orifice (a disk with a hole through which fluid can flow), or an adjustable needle valve.
- Needle valves are designed to give fine control of flow in small diameter piping. The symbol for a needle valve is a variable orifice.

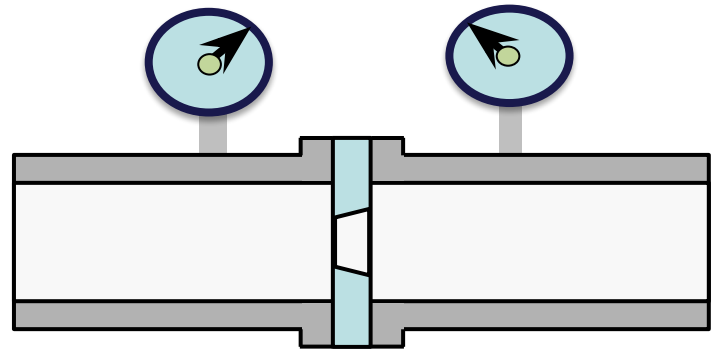


$$Q = vA$$



Orifice As a Flow Control Element

- Recall that from Darcy equation, when fully turbulent flow exists for a fluid with density ρ in a pipe with diameter D and length L , the following relationship exists for the pressure drop, Δp across the pipe, where f is the friction factor and Q is the volumetric flow rate. The parameter K_{pipe} is a coefficient that depends on the pipe surface finish and pipe geometry.
- A similar relationship exists for any valve or fitting with K_{pipe} replaced with K_v where K_v is a geometric and material parameter for the valve or the fitting. It is called the valve flow coefficient.



$$\Delta p = f(L/D)(\rho v^2 / 2)$$

$$\Delta p = (8 f L / \pi^2 D^5) \rho Q^2$$

$$f \approx \left(4 \log \left(\frac{\varepsilon / D}{3.7} \right) \right)^{-1}$$

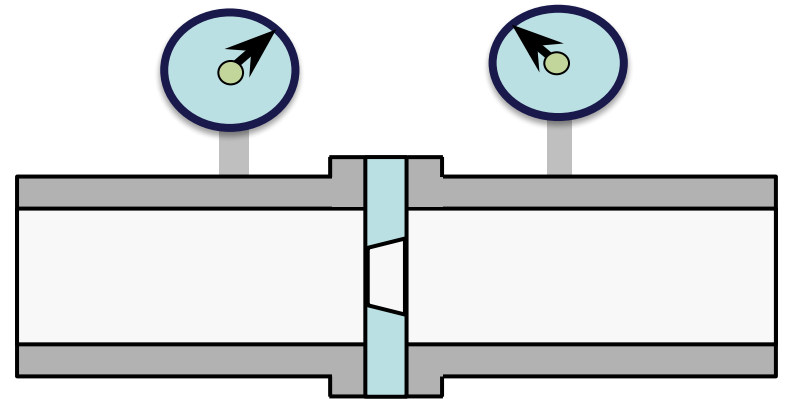
$$Q = K_{pipe} \sqrt{\Delta p / \rho}$$

$$K_{pipe} = \sqrt{\pi^2 D^5 / 8 f L}$$

$$Q = K_v \sqrt{\Delta p / \rho}$$

Orifice As a Flow Control Element

- An orifice is a disk with a hole through which fluid can flow. An orifice can be used as a flow meter by measuring the pressure drop across the orifice.
 Q : Flow rate (Liter per minute)
 Δp : Pressure drop (kPa)
 A : Orifice area (mm²)
- An orifice can be used as a flow control device. For a given pressure drop, the smaller the orifice, the smaller will be the flow rate, and vice versa.



$$Q = K_{Orifice} \sqrt{\Delta p / \rho}$$

$$K_{Orifice} = 2.15 A, \text{ sharp edge orifice}$$

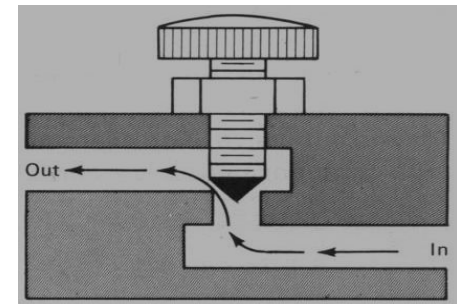
$$K_{Orifice} = 1.61 A, \text{ square edge orifice}$$

Needle Valves

- For a given opening position, the needle valve behaves like an orifice. Unlike the orifice, the flow area, A , in the needle valve can be varied.
- The equation for the flow rate vs. pressure drop for the needle valve is as shown, where
 - Q : Flow rate (Liter per minute)
 - Δp : Pressure drop (kPa)
- The valve flow coefficient determines the amount of flow that can go past a valve when the valve is fully open. The value of the valve coefficient for a particular valve is usually distributed by valve manufacturers and it is determined experimentally.

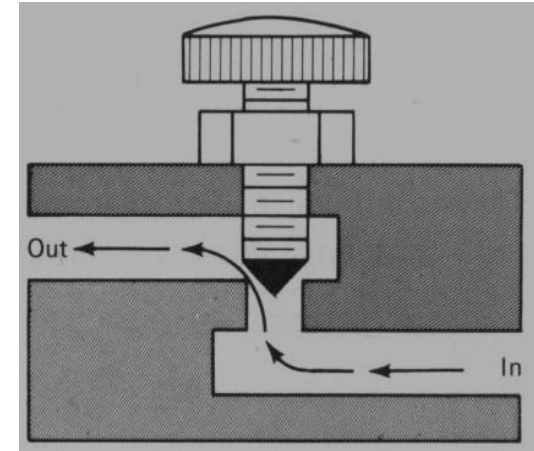
$$Q = K_V \sqrt{\Delta p / \rho}$$

K_V = Valve flow coefficient

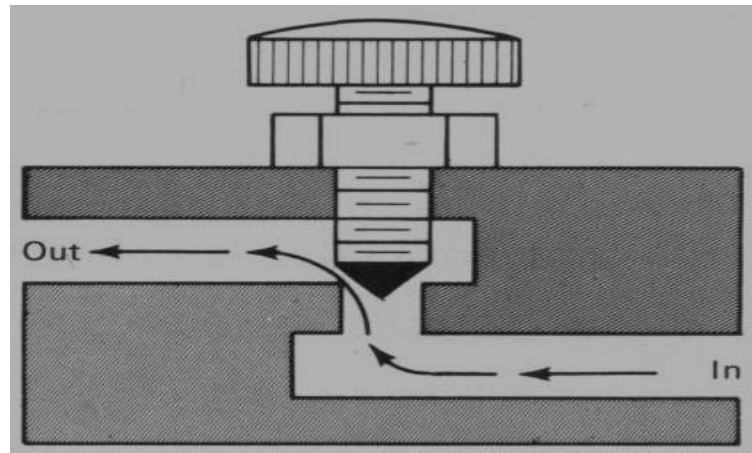


Sizing a Flow Control Valve

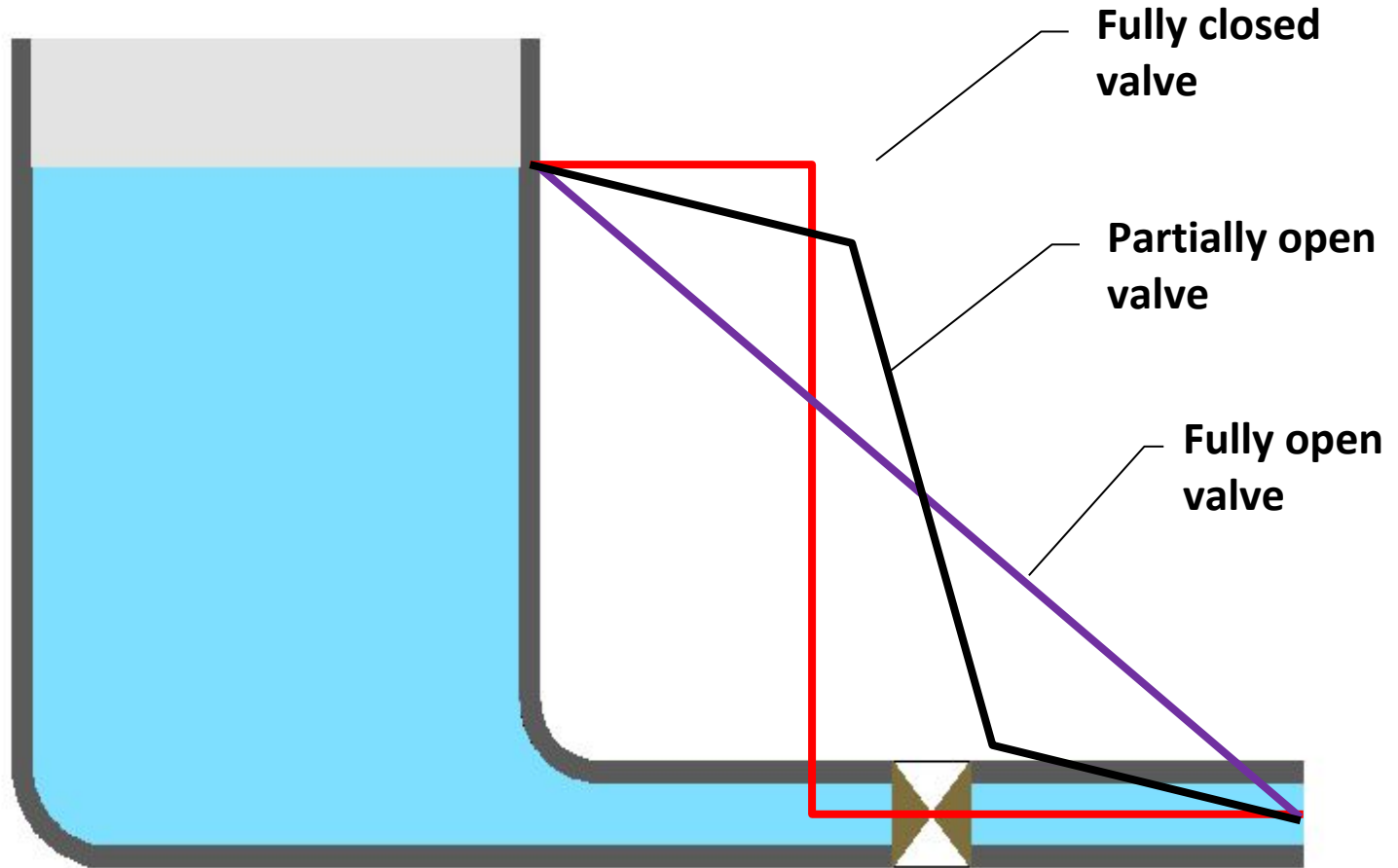
- If a control valve is undersized, a large pressure loss would take place across the valve when it is fully open. The pump would require a large amount of power to pass the oil through the fully open valve.
- If the valve is oversized, the initial travel from fully open position would produce little or no effect on the flow rate. When a point is reached where the valve would influence the flow rate, small increment in valve position would produce large effect on the flow rate, making it difficult to control the flow.
- A compromise is needed between power loss across the valve and good control.



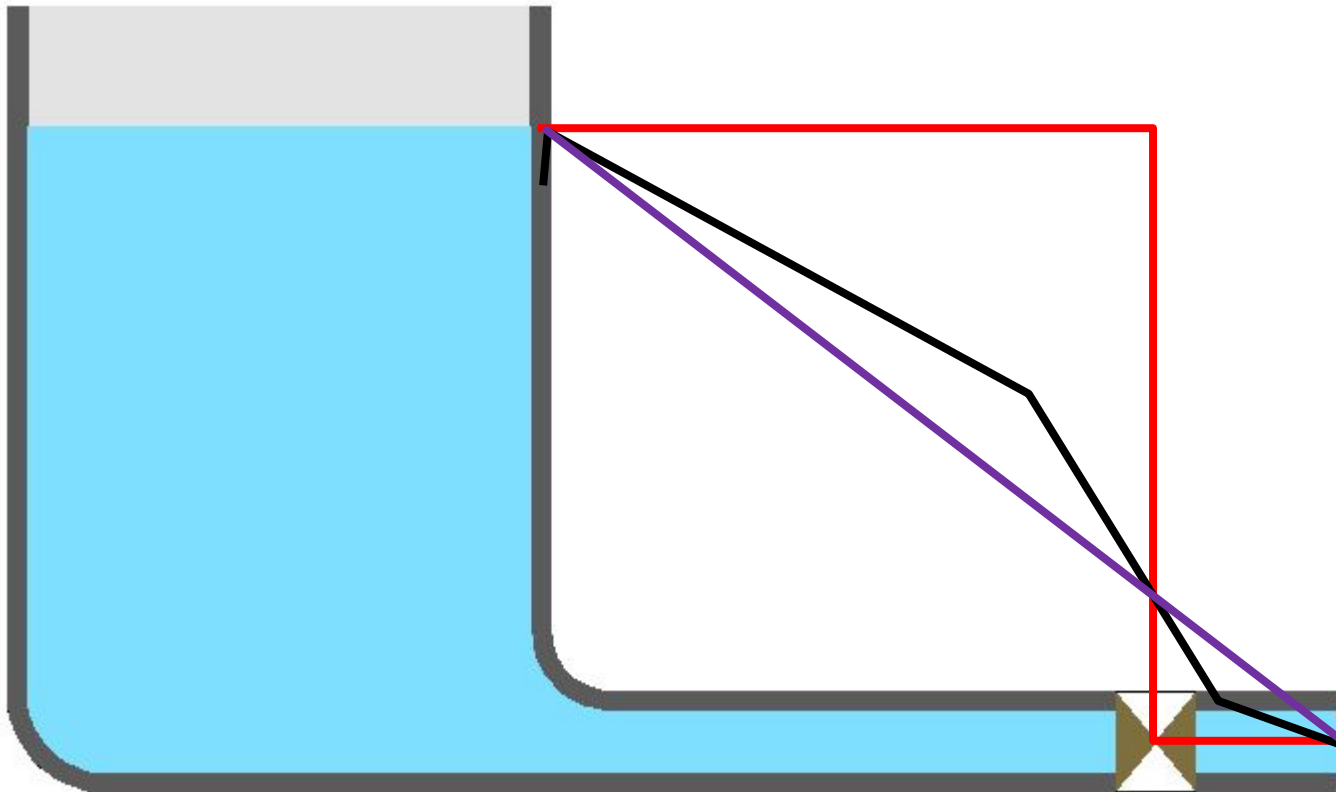
Sizing a Flow Control Valve



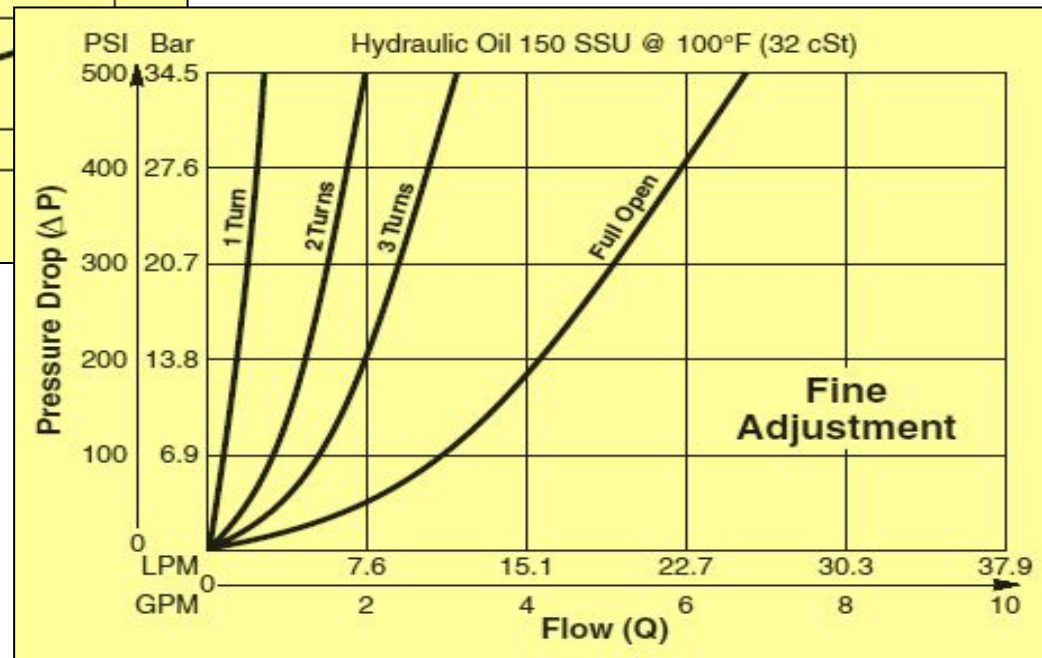
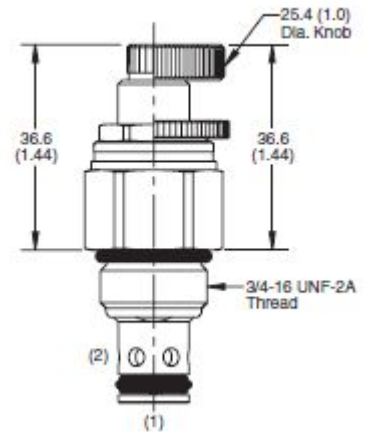
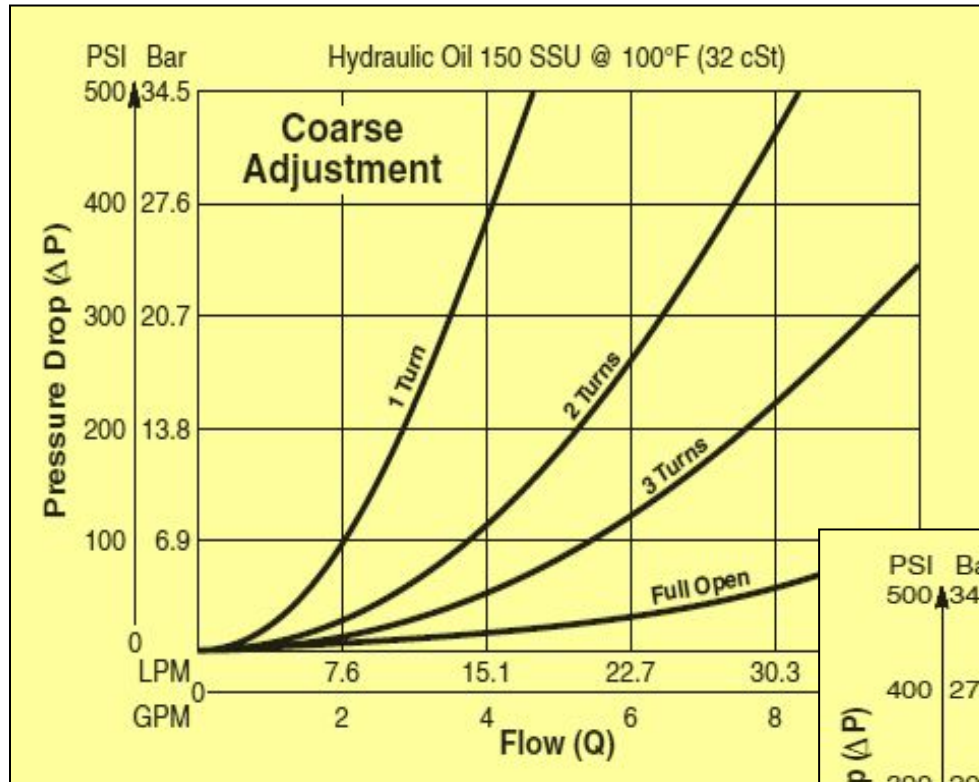
Pressure Distribution along a pipe with a Control Valve



Pressure Distribution along a pipe with a Control Valve



Flow Rate vs. Pressure Drop in a Control Valve



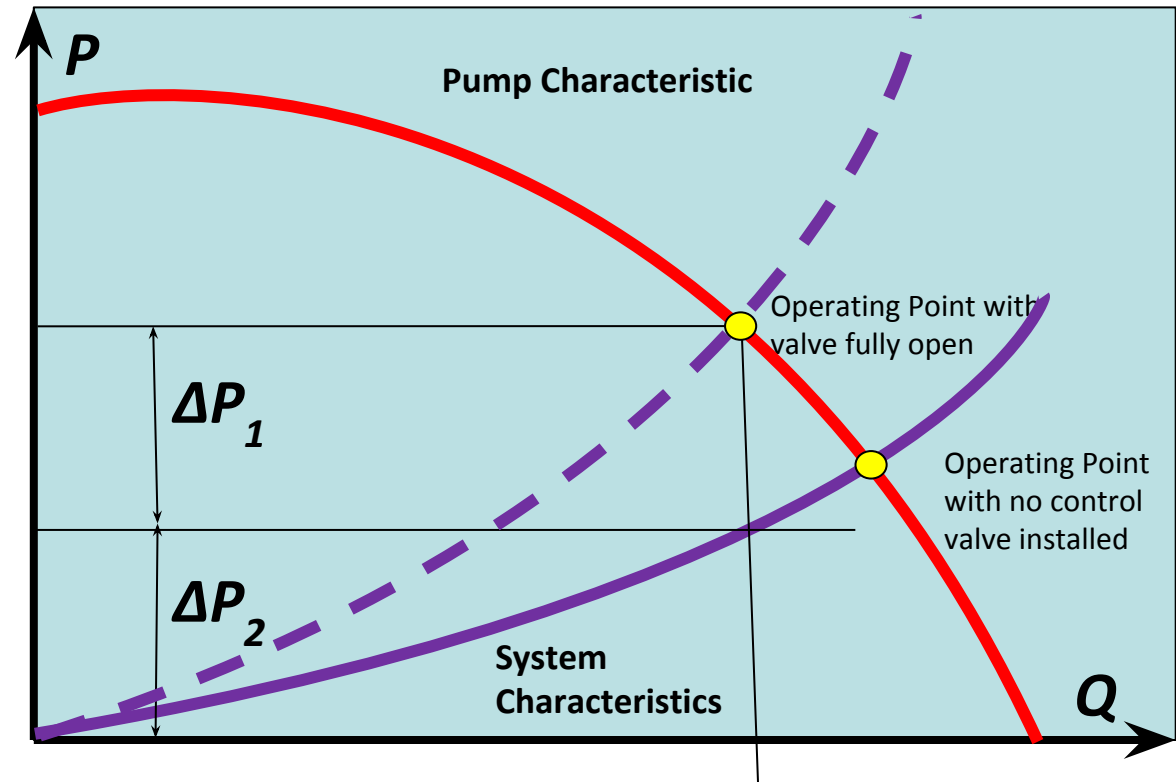
Sizing a Flow Control Valve

ΔP_1 : Pressure drop
across a fully
open control
valve

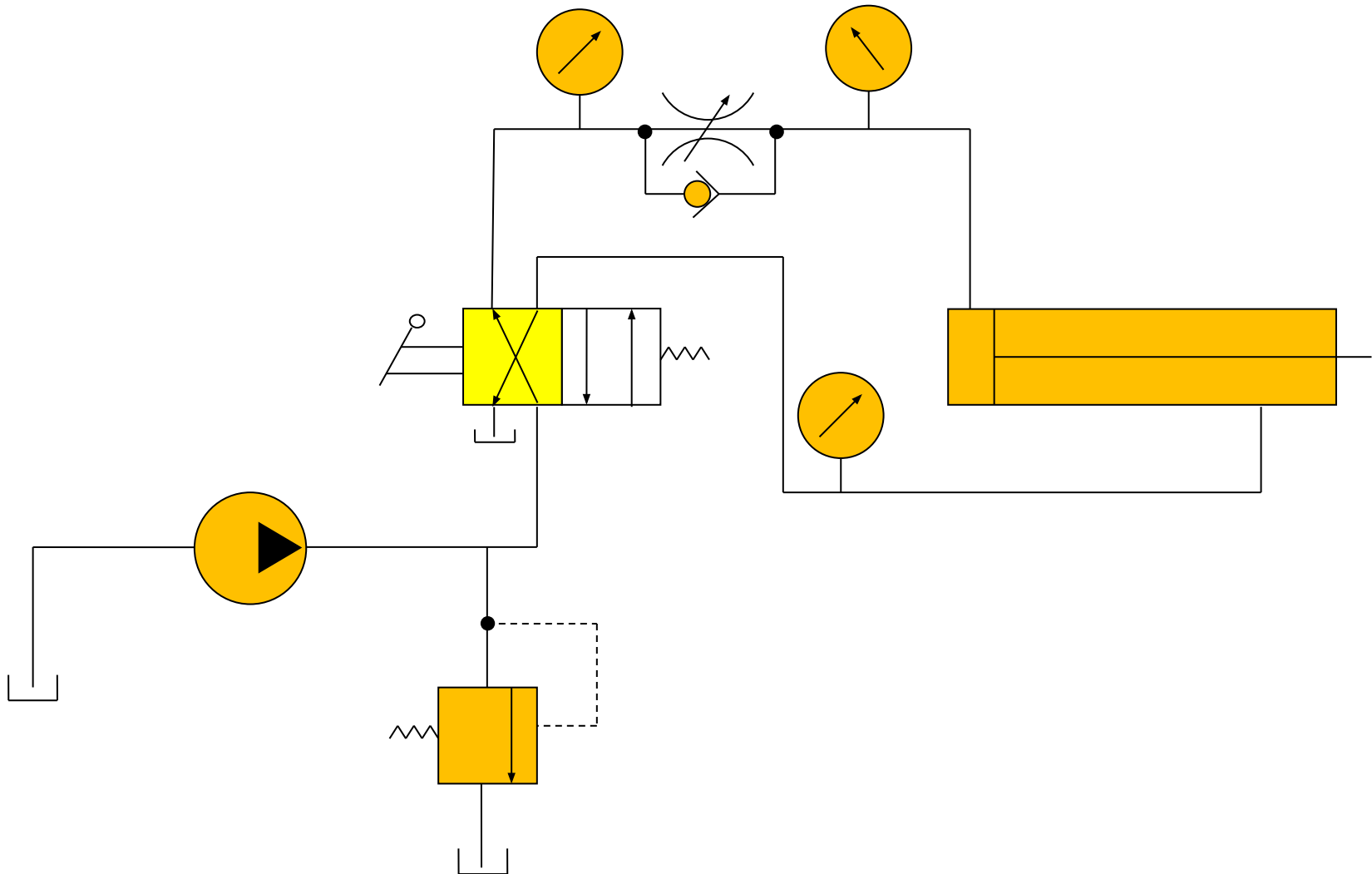
ΔP_2 : Pressure drop
across the
remainder of the
circuit

$$n = \frac{\Delta p_1}{\Delta p_1 + \Delta p_2},$$

$$0.2 \leq n \leq 0.5$$

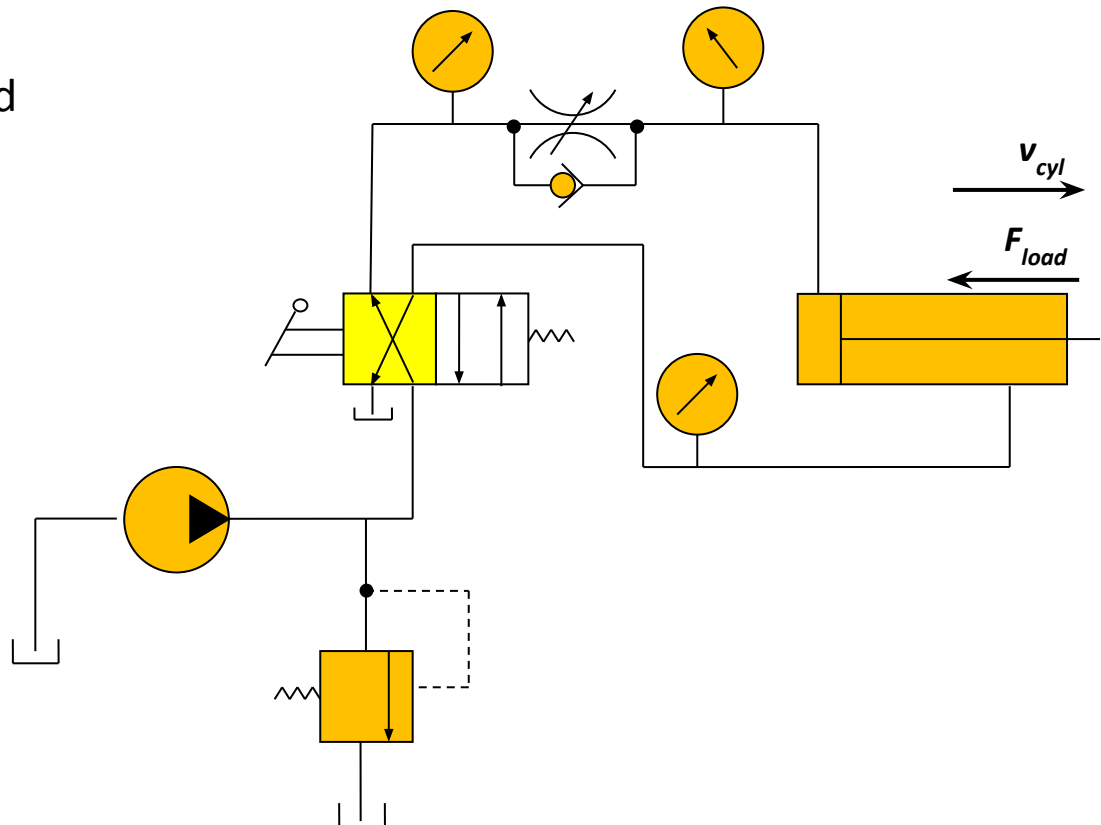


Speed Control of a Hydraulic Cylinder using a flow control valve (Meter-In)



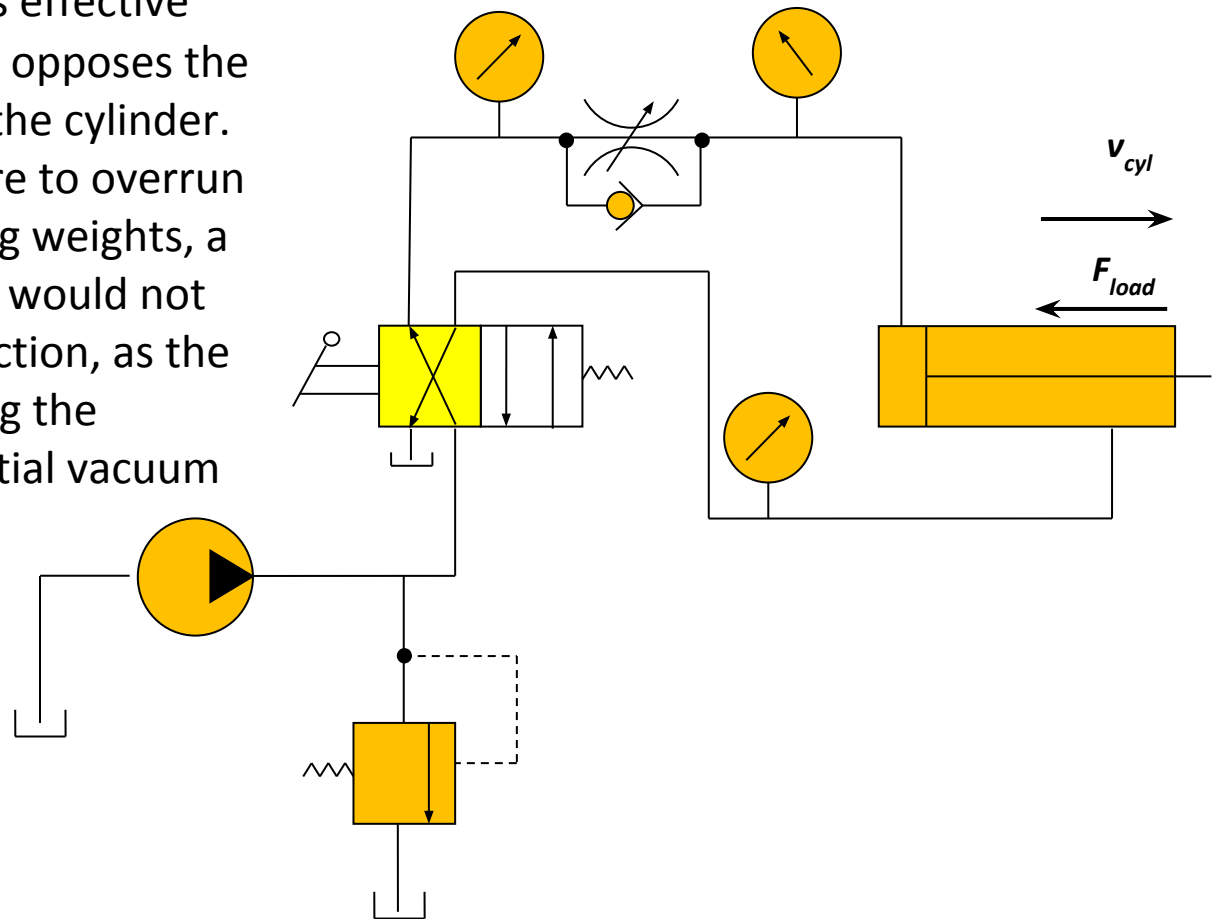
Speed Control of a Hydraulic Cylinder using a flow control valve (Meter-In)

- The flow control valve (FCV) restricts the rate of flow into the cylinder during the extension stroke. The extending speed of the cylinder depends on the setting (percent of full opening) of the flow control valve .
- When the directional control valve is deactivated, the cylinder retracts unrestricted as flow passes through the check valve and the flow control valve



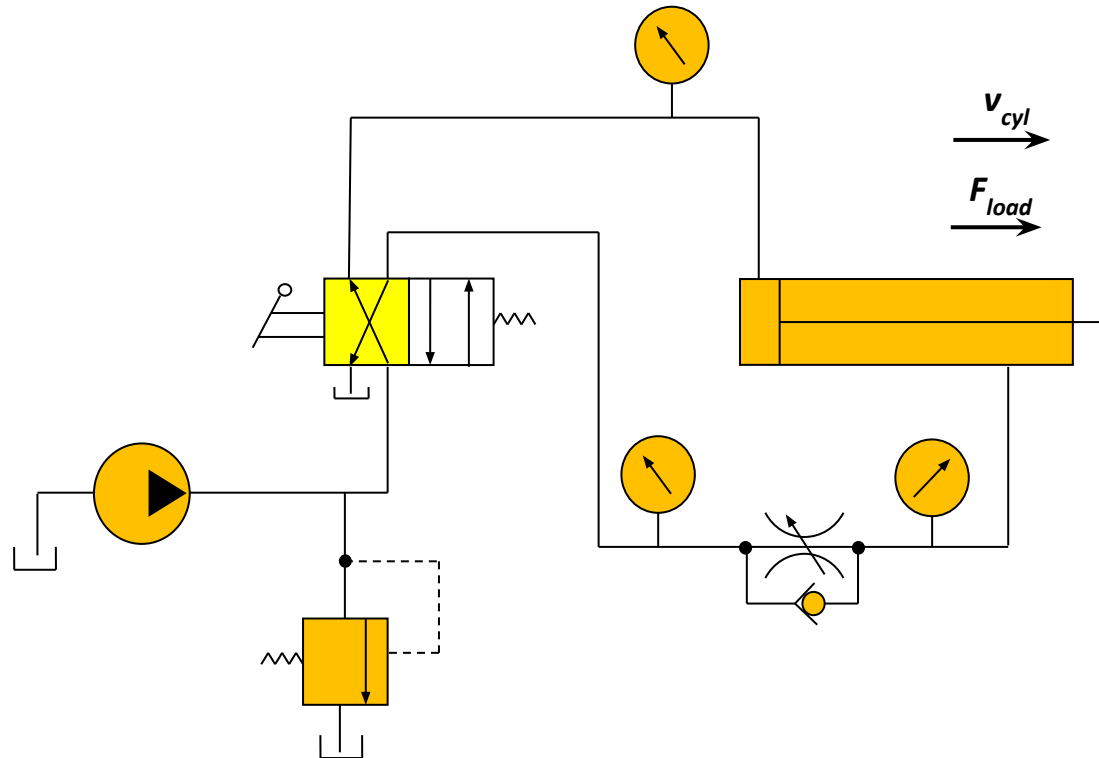
Speed Control of a Hydraulic Cylinder using a flow control valve (Meter-In)

- The circuit is an example on a meter-in flow control system. In this system, the flow control valve offers resistance to the flow getting into the cylinder.
- Meter-in flow control is effective when the external load opposes the direction of motion of the cylinder. If the external load were to overrun the cylinder, as in falling weights, a meter-in speed control would not offer the needed restriction, as the load will keep extending the cylinder, creating a partial vacuum inside.



Speed Control of a Hydraulic Cylinder using a flow control valve (Meter-Out)

- In a meter-out circuit, the flow control element restricts the outlet flow of the cylinder. Meter out circuits do offer resistance to overrunning load.
- One drawback in meter-out circuits is the possibility of excessive pressure build-up in the rod end of the cylinder while extending. The rod side pressure may exceed the pump pressure if a single-rod cylinder is used in which the power stroke proceeds towards the rod side. A high pressure in the rod side would result in high heat generation and increase the oil temperature

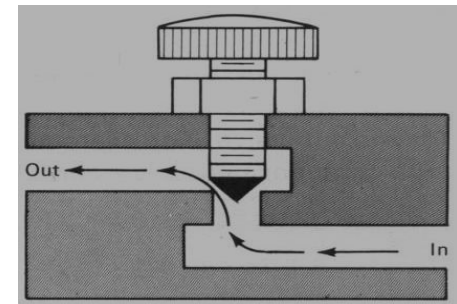


Pressure Compensated Valves

- If the load on an actuator changes significantly, system pressure will change appreciably. In a simple, non-pressure compensated flow control valve, the flow rate through the valve will change at the same valve setting.
- A pressure compensated flow control valve incorporates a design feature, which allows it to maintain an almost constant flow rate in spite of changes in pressure difference across the valve.

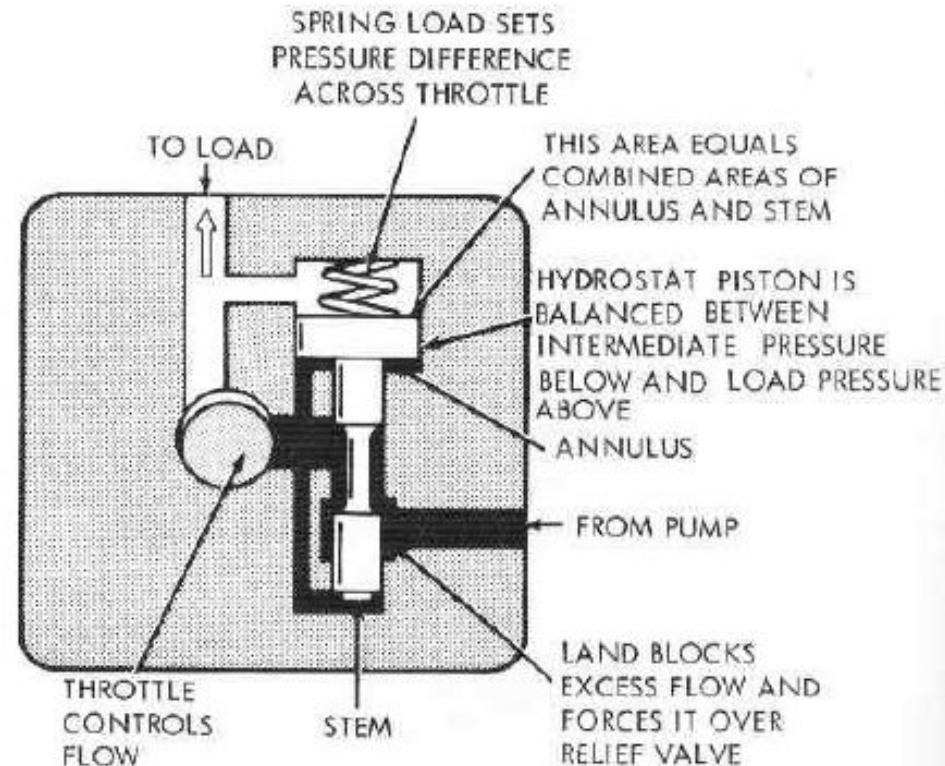
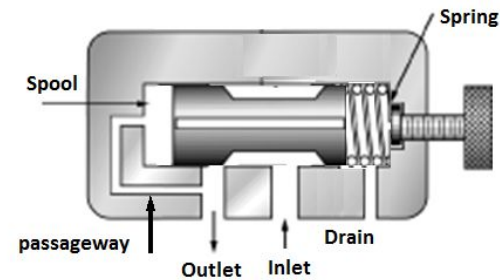
$$Q = K_V \sqrt{\Delta p / \rho}$$

K_V = Valve flow coefficient



Pressure Compensated Valves

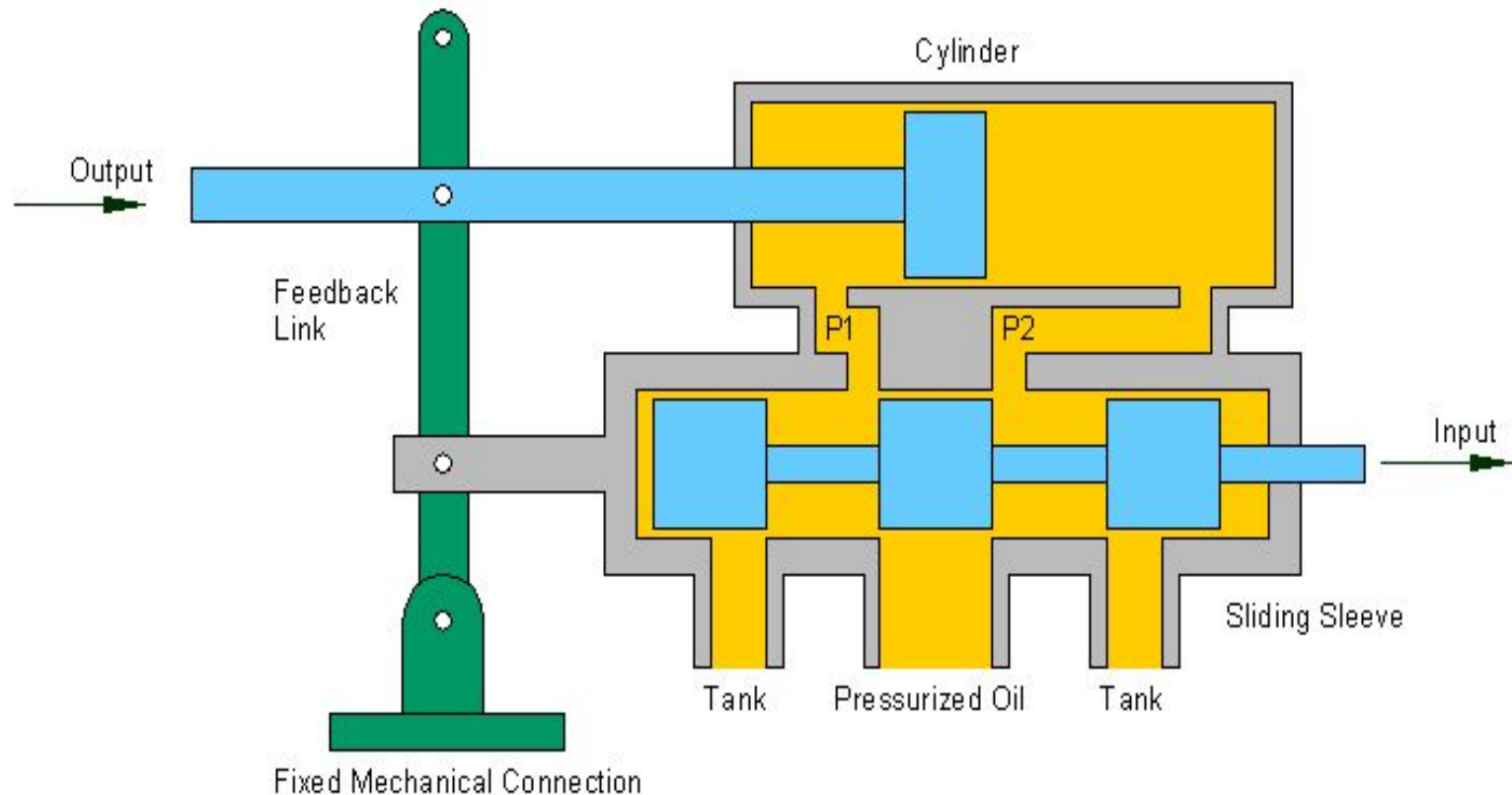
- The design incorporates a hydrostat that maintains a constant pressure difference across the throttle, which is an orifice, whose area can be adjusted by an external knob setting.
- The orifice area setting determines the flow rate to be controlled. The hydrostat acts as a pressure reducing valve, which maintains constant pressure difference across the orifice irrespective of external line pressure variations.



Servo Valves

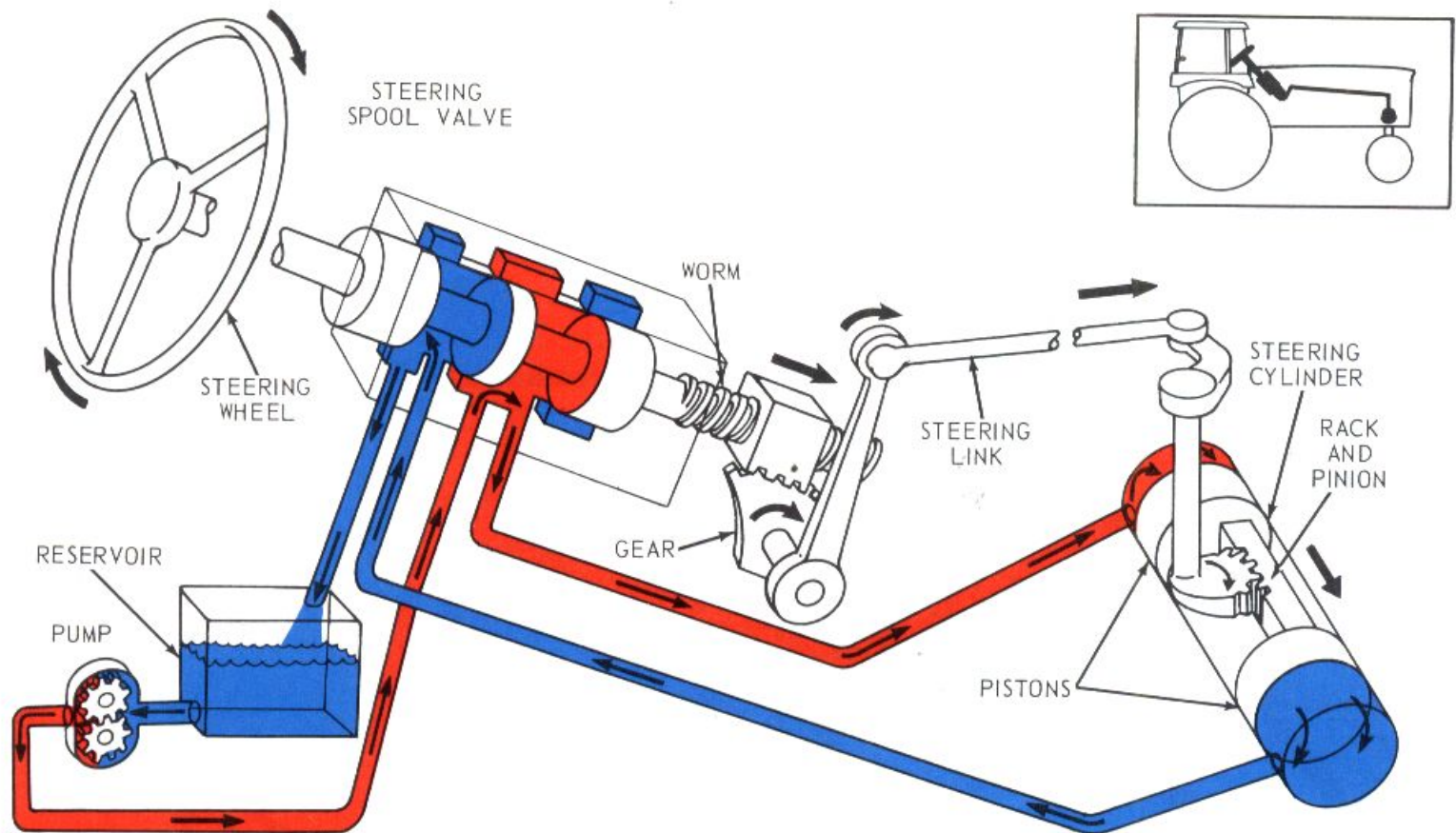
Servo Valves

- A servo valve is a valve of the directional-control type, that is coupled with a feedback sensing device to allow very accurate control of position, velocity or acceleration of an actuator with small input force.



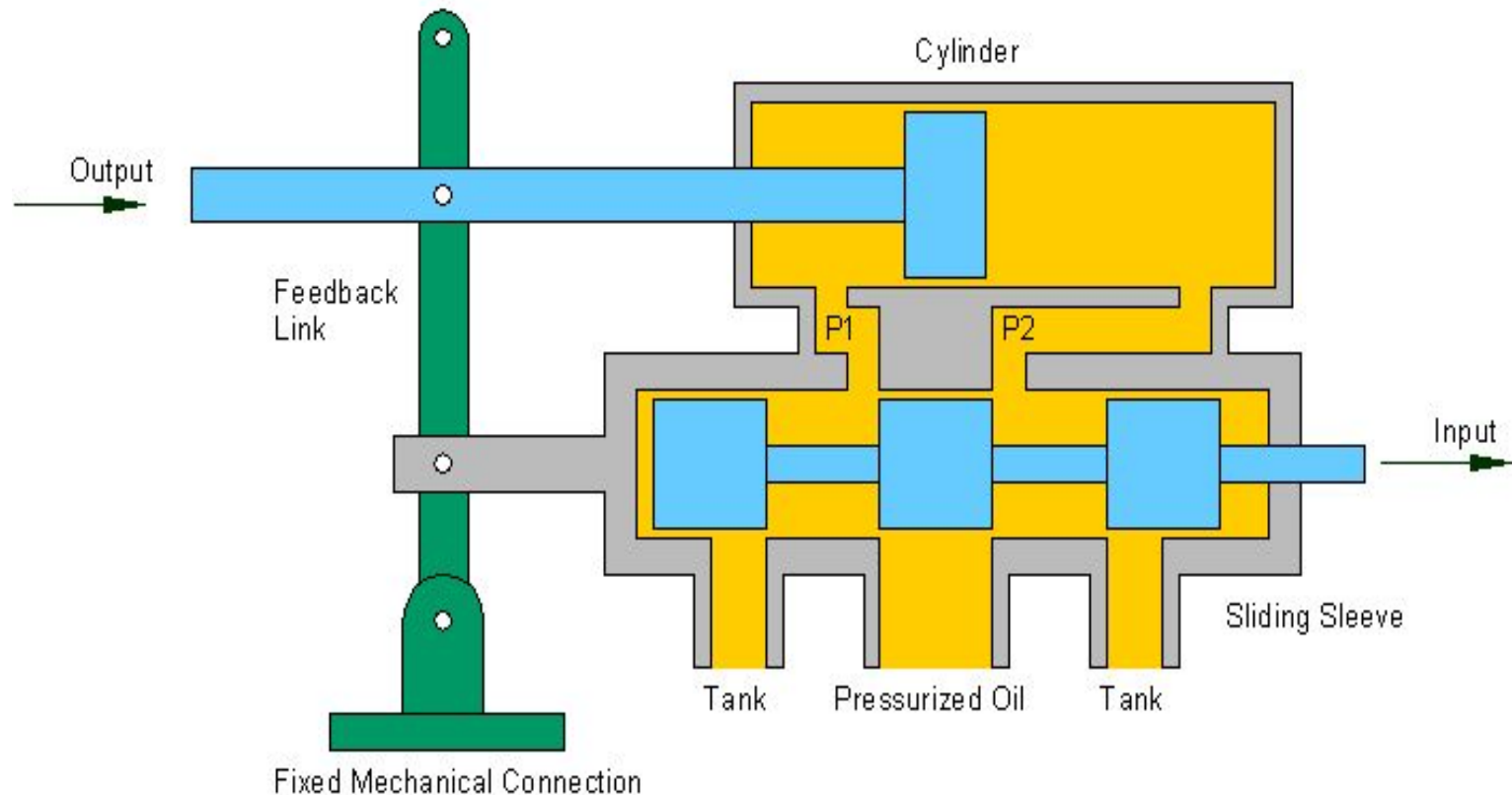
Servo Valves

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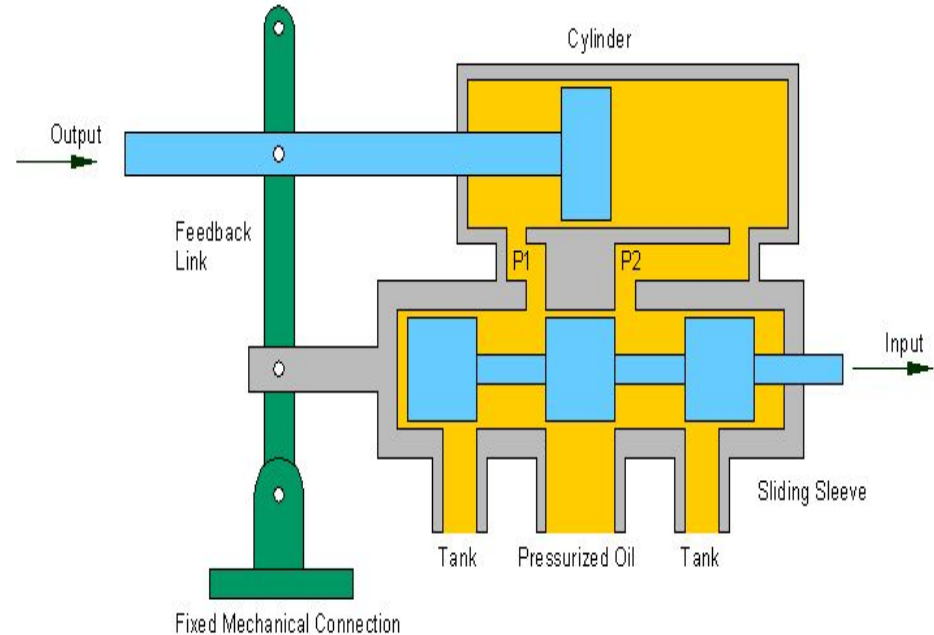
Servo Valves

- The valve shown is a mechanical type servo valve, which is essentially a force amplifier used for positioning control.



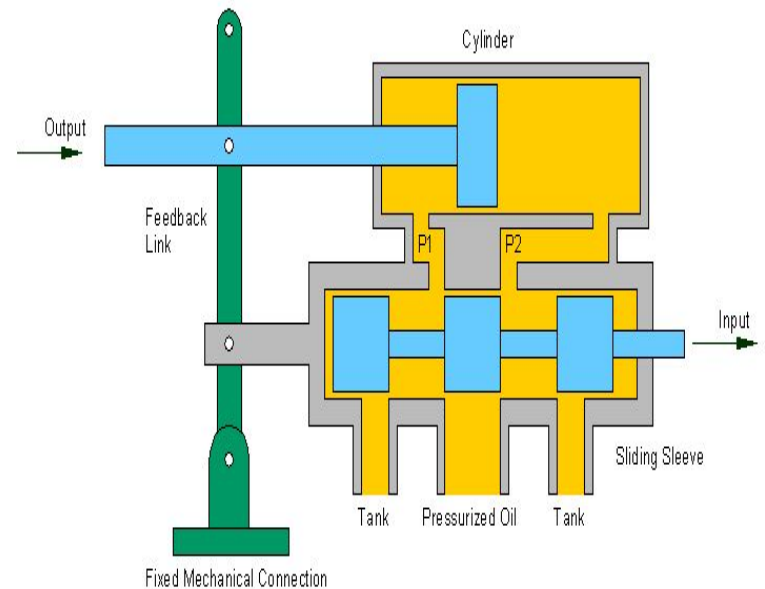
Servo Valves

- A small amount of input force shifts the spool of the servo valve to the right by a specified amount. The oil then flows through port *P1* retracting the hydraulic cylinder to the right.
- The action of the feedback link shifts the sliding sleeve to the right until it blocks off the flow to the hydraulic cylinder. Thus a given input produces a specific and controlled amount of motion output.
- One of the common applications of servovalves is the hydraulic power steering systems of automobiles.



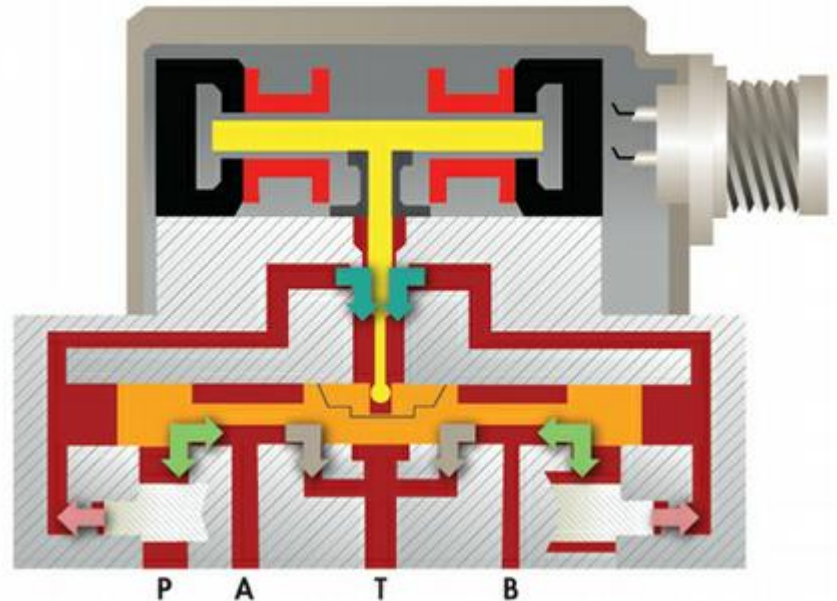
HW 3

- For the servo valve shown,
- Assume pertinent dimensions
- Derive the static (steady) relationship between the input motion and the output motion in terms of geometric dimensions.
- Analyze the dynamic relationship between the input motion and output motion in terms of link dimensions and flow rate through the valve. (Assume infinite bulk modulus)
- Assuming a finite bulk modulus. Derive the relationships between the input and the output for (i) step change in input position, and (ii) ramp change in input position, and (iii) harmonic change in input position.



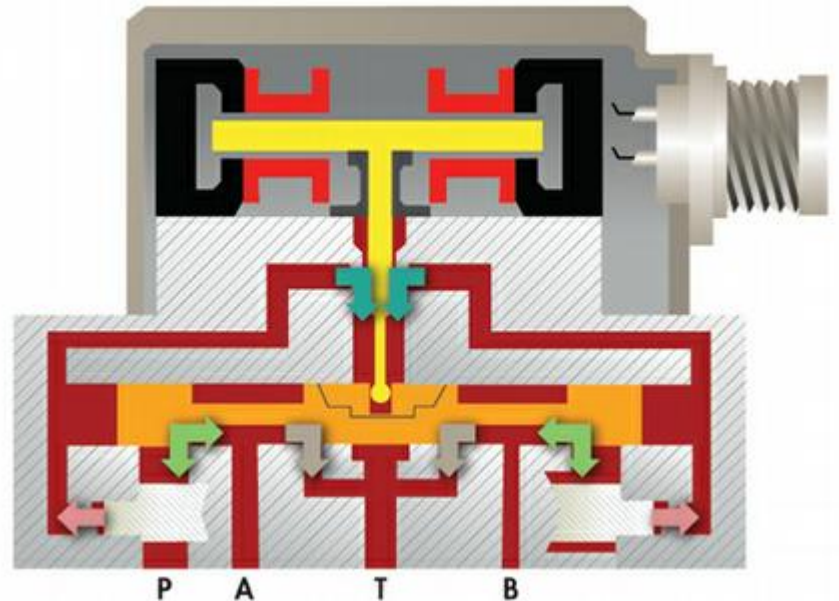
Electrohydraulic Servo Valves

- Electrohydraulic servo valves have a four-way directional valve with a spool displacement proportional to the input electrical current. The valve uses an electric torque motor along with a sliding spool fed from a double nozzle pilot stage to provide this functionality.
- The torque motor includes coils, pole pieces, magnets and armature. The armature is supported for limited movement by a flexure tube, which also provides a seal between the hydraulic and electromagnetic portions of the valve.



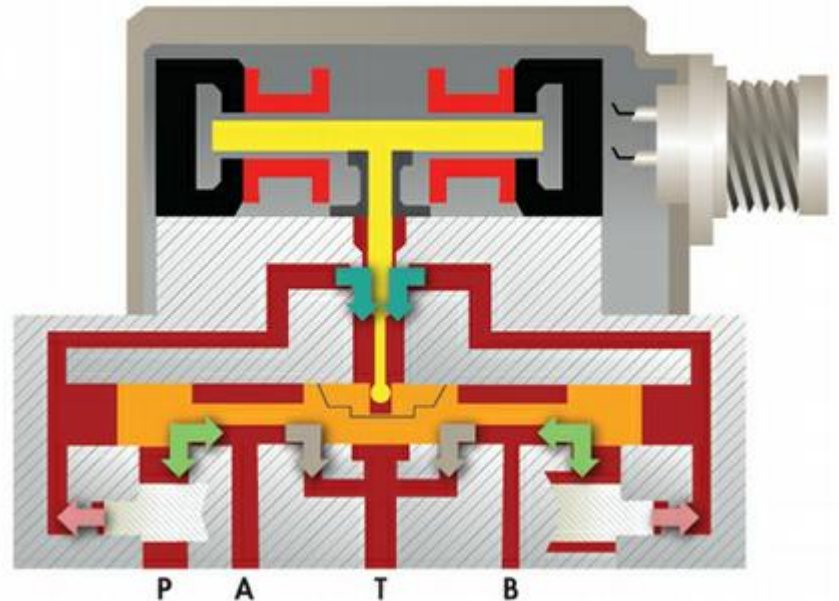
Electrohydraulic Servo Valves

- The flapper attaches to the center of the armature and extends down inside the flexure tube. A nozzle is located on each side of the flapper so that flapper motion varies with nozzle openings.
- Pressurized hydraulic fluid is supplied to each nozzle through an inlet orifice located in the end of the spool. Differential pressure between the ends of the spool is varied by flapper motion between the nozzles



Electrohydraulic Servo Valves

- The four-way valve spool directs flow supply to either control port A or T in an amount proportional to spool displacement.
- The spool contains flow metering slots in the control lands that are uncovered by spool motion. Spool movement deflects a feedback wire that applies a torque to the armature/flapper. Spool detent springs center the spool whenever hydraulic driving pressures are absent



Electrohydraulic Servo Valves

- Electrical current in the torque motor coils causes either clockwise or counterclockwise torque on the armature. This torque displaces the flapper between the two nozzles. The differential nozzle flow moves the spool to either the right or the left.
- The spool continues to move until the feedback torque counteracts the electromagnetic torque. At this point, the armature/flapper returns back to the center, so the spool stops and remains displaced until the electrical input changes to new level. The valve spool position is proportional to the electrical signal. The actual flow from the valve to the load is proportional to the load pressure.

