MENG2520 Pneumatics and Hydraulics

Module 3 – Hydraulic Equipment

-Hydraulic Control Devices

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Hydraulic Equipment – Hydraulic Control Devices

The control devices in the hydraulic system provide a means of controlling the direction, pressure and flow rates of the fluid, resulting ultimately in the control of the actuators

In this Module we will study

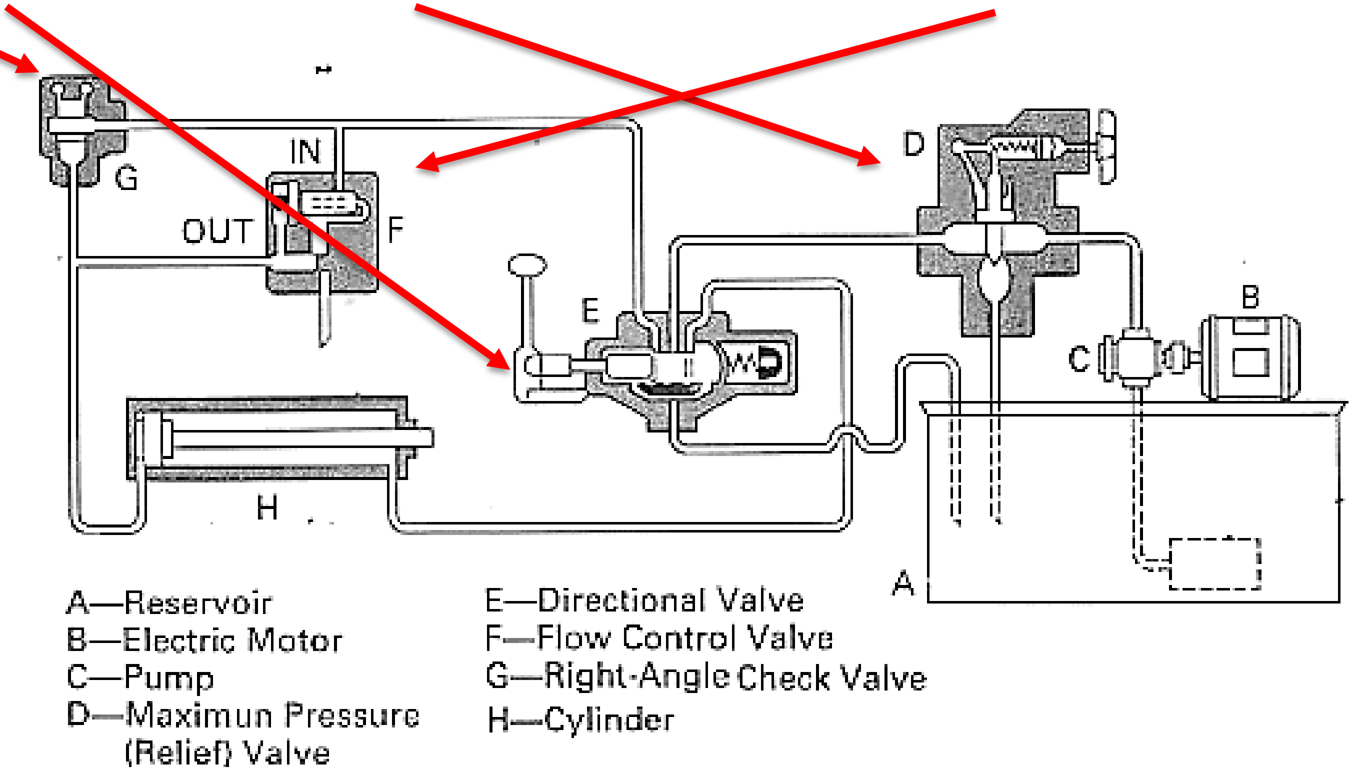
- **Directional Control Valves**
- **Pressure Control Valves**
- **Flow Control Valves**

The Hydraulic Control Devices

Hydraulic control devices are used to control the direction, pressure and flow rate of the hydraulic fluid. In doing so, the direction, force and speed of the actuator is controlled

There are three classes of hydraulic control devices

Directional **Pressure** **Flow**



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The Hydraulic Control Devices

Directional control valves determine the path through which a fluid traverses a given circuit.

- check valves
- two-way, three-way, and four-way directional control valves
- shuttle valves

Pressure control valves protect the system against overpressure, which may occur due to excessive actuator loads or due to the closing of a valve.

- pressure relief
- pressure reducing
- sequence
- unloading
- counterbalance valves

Flow rate control valves determine the rate of fluid flow which results in the speed control of the actuators

- Non-compensated flow control valves
- Pressure-compensated flow control valves

https://summit-hydraulics.com/product/monoblock-hydraulic-directional-control-valve-5-spool-11-gpm/
https://ph.parker.com/us/en/pressure-relief-valves
https://ph.parker.com/us/en/in-line-flow-control-valve-f-series

Directional Control Valve

https://summit-hydraulics.com/product/monoblock-hydraulic-directional-control-valve-5-spool-11-gpm/

8.2 Directional Control Valve

The Direction Control Valve (DCV) is used to direct the flow of hydraulic oil through the hydraulic circuit to achieve the desired function of cylinder extension/retraction or motor direction.

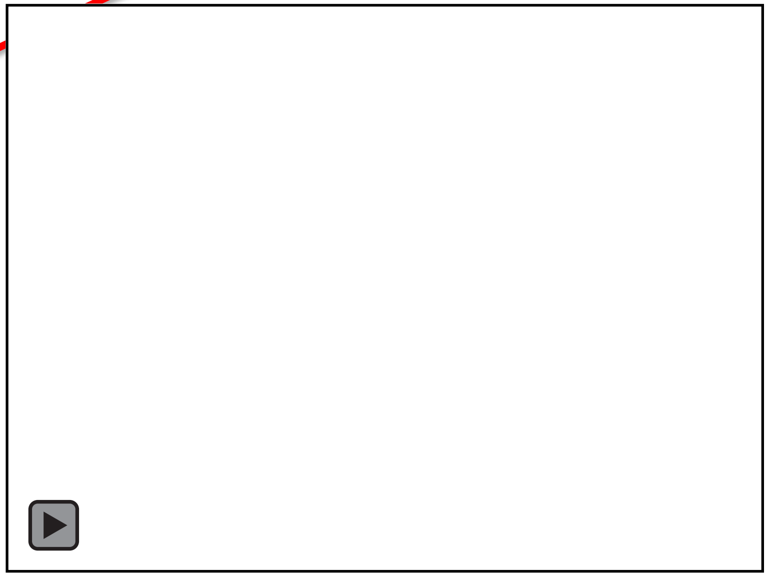
The valves are described by the number of **connection ports, or ways, and positions**

They can be as simple as one-way check valve, to multi-port manual or solenoid controlled

https://ph.parker.com/us/en/general-purpose-check-valve-c-series

https://summit-hydraulics.com/product/monoblock-hydraulic-directional-control-valve-5-spool-11-gpm/

http://www.hoyea.com/products/Electro-hydraulic-directional-control-valve.htm



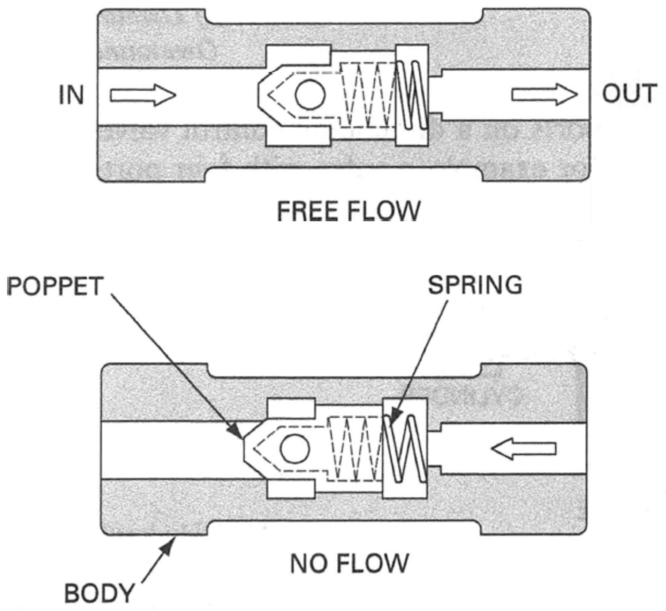
8.2 Check Valve

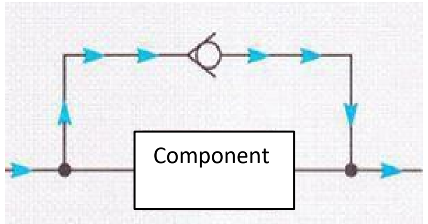
The simplest type of directional control is a **Check Valve**
It permits *free flow* in one direction and *prevents flow* in the opposite direction

It has 2 ports (or ways) connecting in-line with the hydraulic circuit

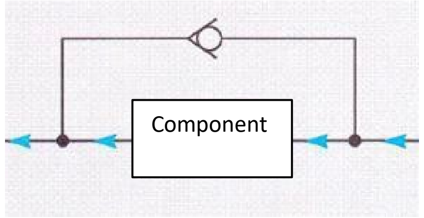
A light spring holds a poppet closed which is released when flow is in the correct direction, and remains sealed when the flow is opposite. Pressure drop to operate is small usually less than 10 psi

Some check valves have ability to override, either manually or through a pilot

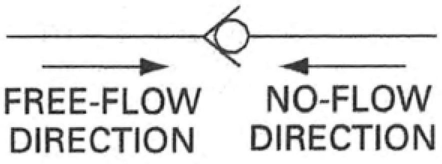




Component bypassed



Flow passes through component



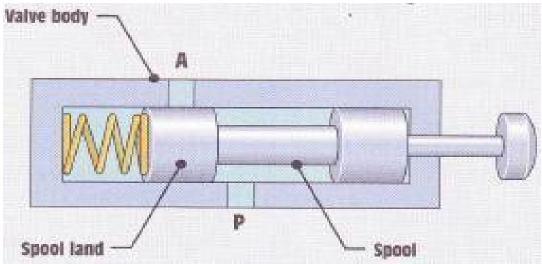
8.2 Multi-Way Valves

Multi-Way valves are used to control the direction of the oil through various ports depending upon the position the valve is in

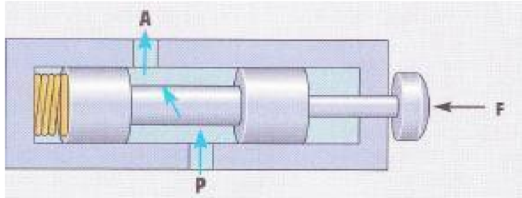
A spool is moved within the valve body to open and close ports, thus directing the oil flow path

A Two-Way valve is the simplest, and can be either normally passing or non-passing

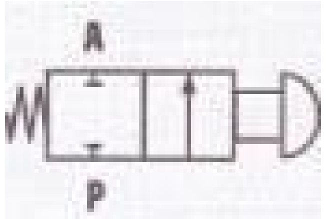
Used as a ‘switch’ in a hydraulic circuit



Normally non-passing valve
With ports P-A blocked



When actuated, oil passes from P to A

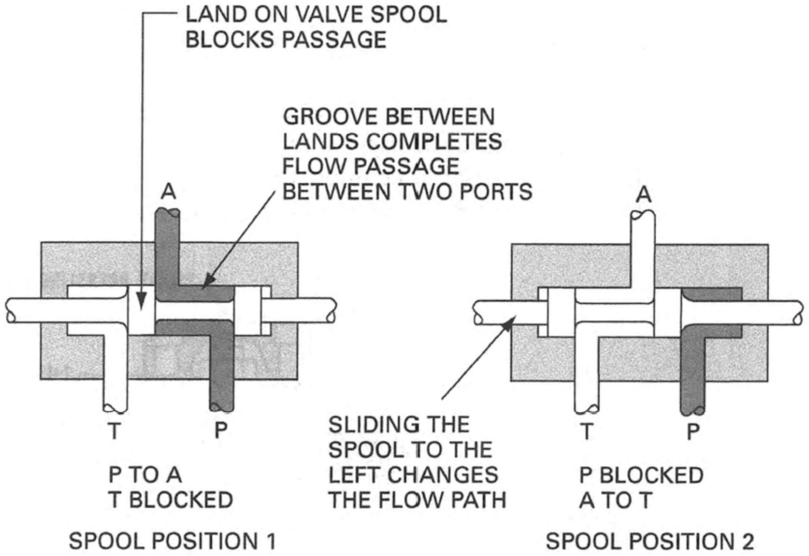


Schematic symbol

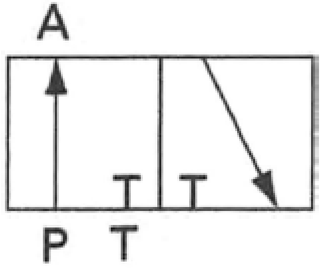
8.2 3-Way Valves

A 3-Way valve controls flow to and from a single output port, with inputs Pressure and Tank

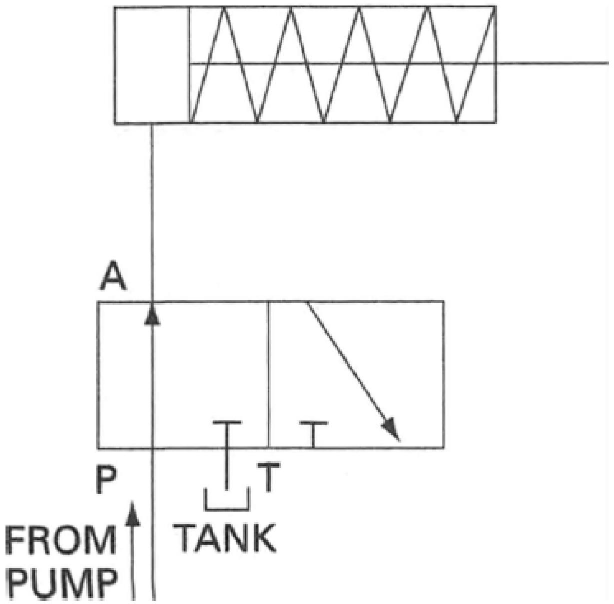
It is generally used to control a single acting cylinder



Operation of a 3-Way valve



Schematic Symbol

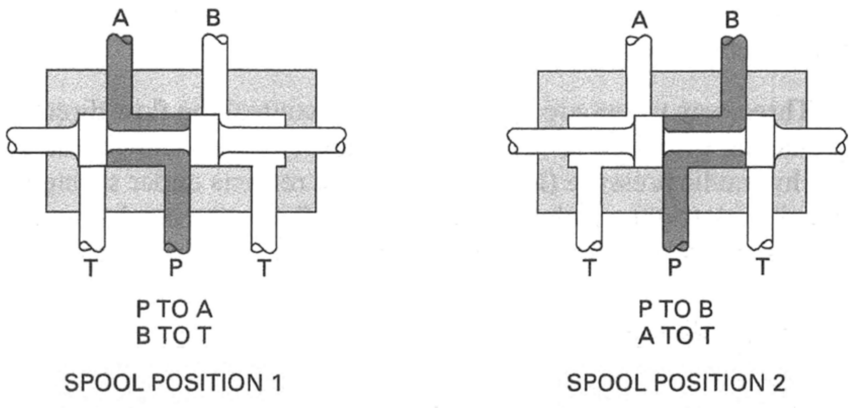


Application with a single acting cylinder

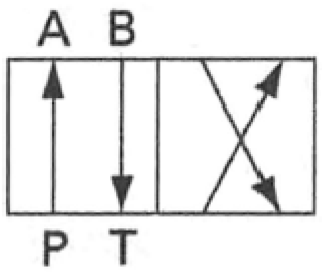
8.2 4-Way Valves

A 4-Way valve controls flow to and from 2 ports, with inputs Pressure and Tank

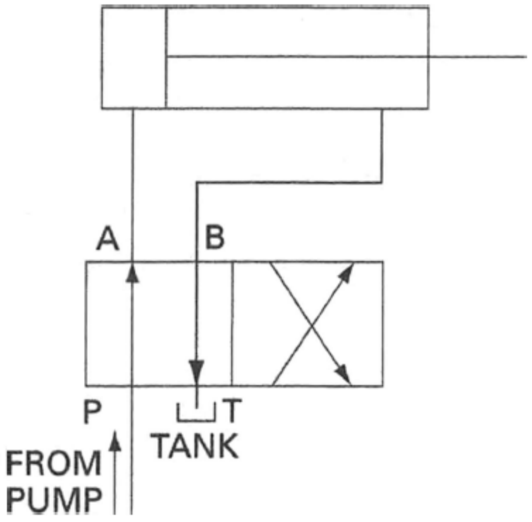
It is generally used to control a double acting cylinder, or motor direction control



Operation of a 4-Way valve



Schematic Symbol

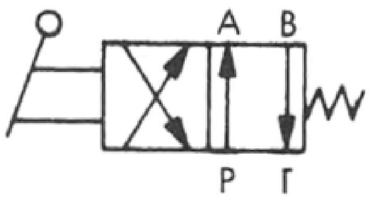


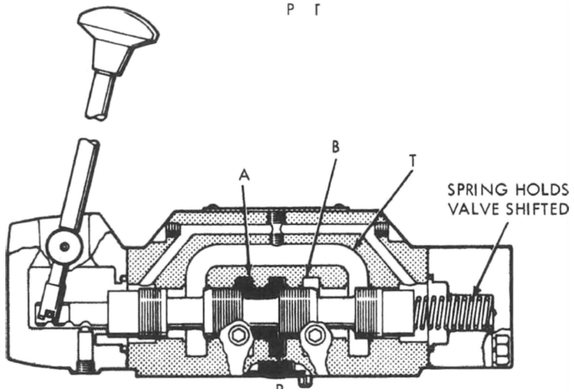
Application with a double acting cylinder

8.2 Multi-Way Valves Actuation

The spool position is determined by applying an external input to the valve, which will shift the spool accordingly. This input can be a variety of things such as manual, lever, spring return, pilot, electrical solenoid

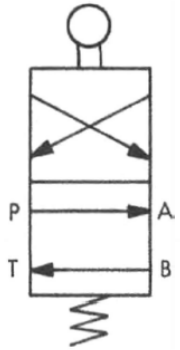
Manually Actuated

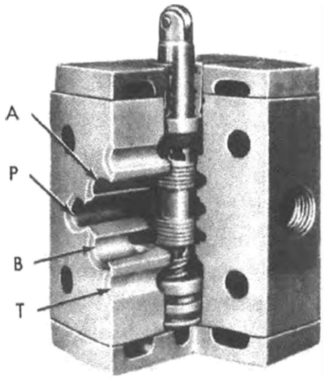




Manual operated, spring return, 4-way, 2 positon valve

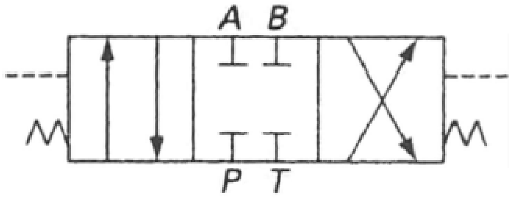
Mechanically Actuated

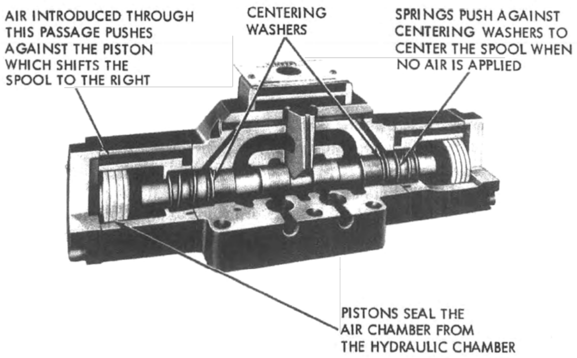




Cam operated, spring return, 4-way, 2 positon valve

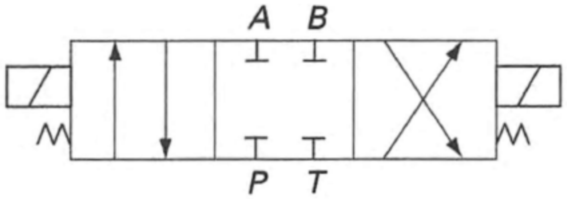
Pilot Actuated





Air pilot-actuated, three-position, spring-centered, 4-way valve

Solenoid Actuated

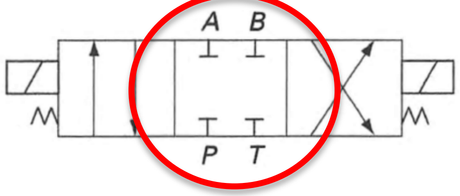


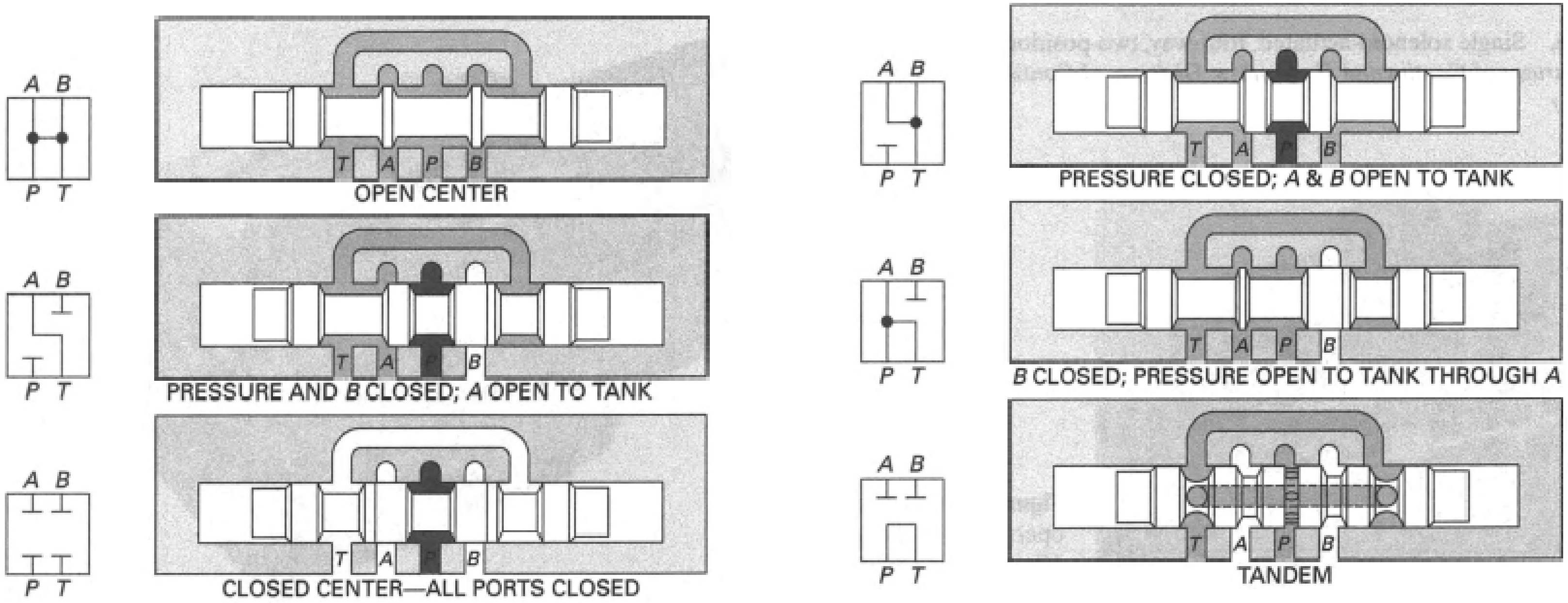
Solenoid operated, spring center, 4-way, 3 positon valve

8.2 Multi-Way Valves Center Position

The center position of a 3-position valve offers different functional behaviors of the systems

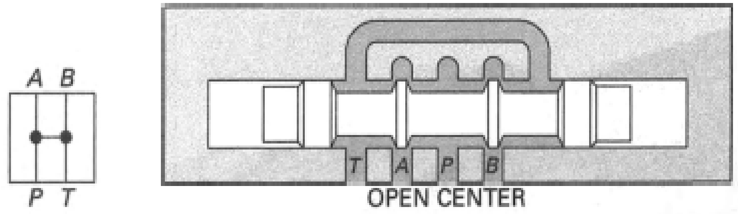
Shown here is a 'Closed Center' DCV which allows cylinder to hold at an intermediate stroke position, locked actuator



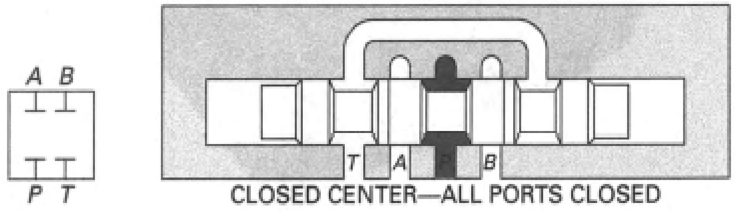


8.2 Multi-Way Valves Center Position

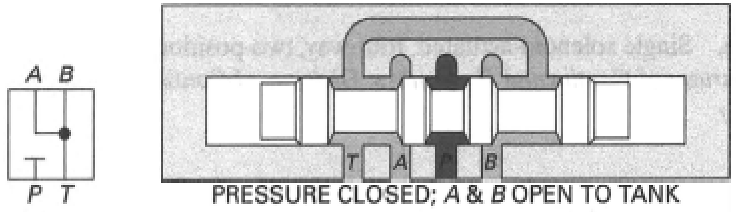
4 Most Common Centers



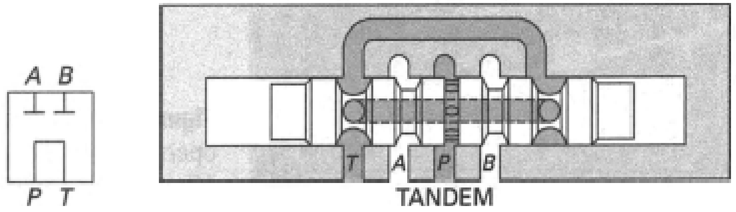
OPEN CENTER
allows the cylinder to move freely
Unloads the pump



CLOSED CENTER
Hydraulically locks the cylinder
Full pump pressure is available to other parts of circuit



FLOAT CENTER
allows the cylinder to move freely
Full pump pressure is available to other parts of circuit



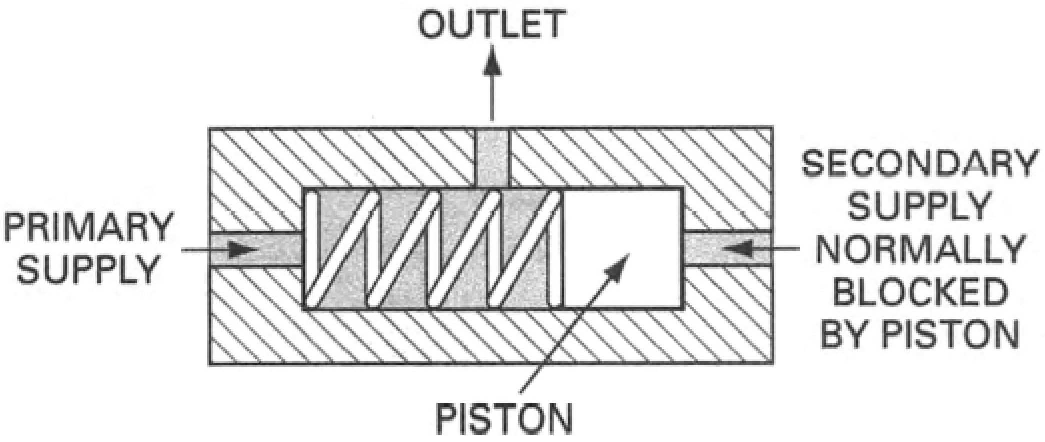
TANDEM CENTER
Hydraulically locks the cylinder
Unloads the pump

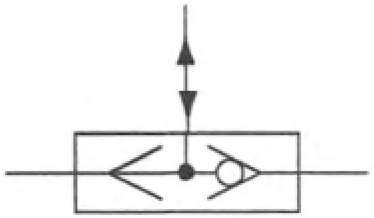
8.2 Shuttle Valve

A shuttle valve permits a system to operate from either of two fluid power sources.

One application is for safety in the event that the main pump can no longer provide hydraulic power to operate emergency devices, a backup pump automatically provides the required power through the shuttle valve.

The shuttle valve will shift to allow fluid to flow from the source with the higher pressure





Schematic Symbol

Pressure Control Valve

https://ph.parker.com/us/en/pressure-relief-valves

8.3 Pressure Control Valve

The Pressure Control Valve (PCV) is used to control the pressure of the hydraulic oil in the entire circuit, or parts of, or even to be used for control action or safety action.

The valves are built and designed into a hydraulic system to achieve a specific and desired function.

Some common types of PCVs are:

Pressure Relief Valve – sets system pressure

Pressure Reducing Valve – lowers pressures hence forces of cylinders

Unloading Valve – Pressure Relief Valve with no-load pump operation

Sequence Valve – controls sequenced operation of multiple cylinders

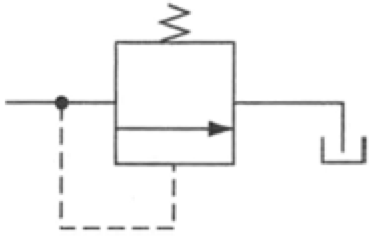
Counterbalance Valve – prevents runaway of loads due to gravity

https://ph.parker.com/us/en/pressure-relief-valves

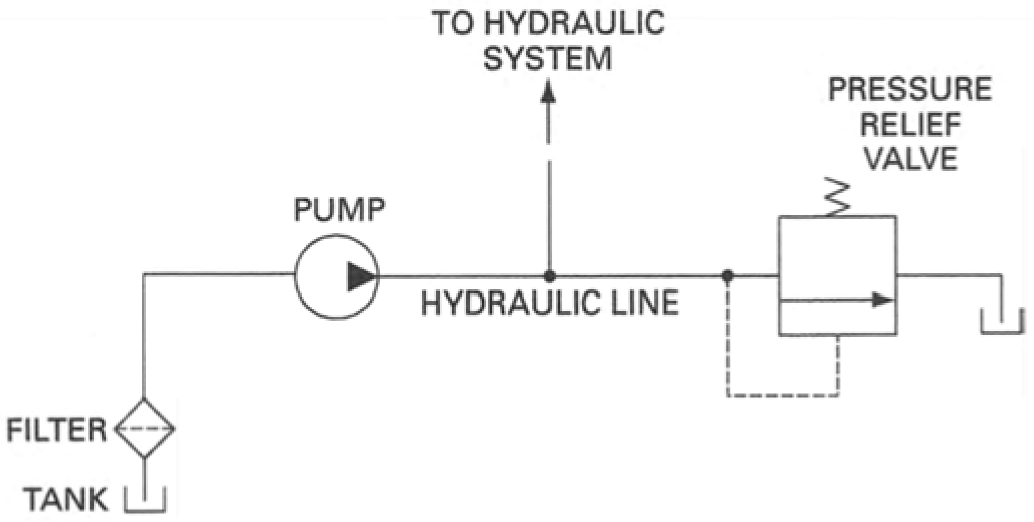
8.3 Pressure Relief Valve

The Pressure Relief Valve is found practically in every hydraulic system to limit the system operating pressure.

As the pump pressurizes the hydraulic oil from the tank into the hydraulic system, the oil pressure would continue to increase to such a point that the pressures could cause damage to the devices and conduits. A Pressure Relief valve limits this system pressure by opening a path back to tank for the oil to pass.



Schematic Symbol

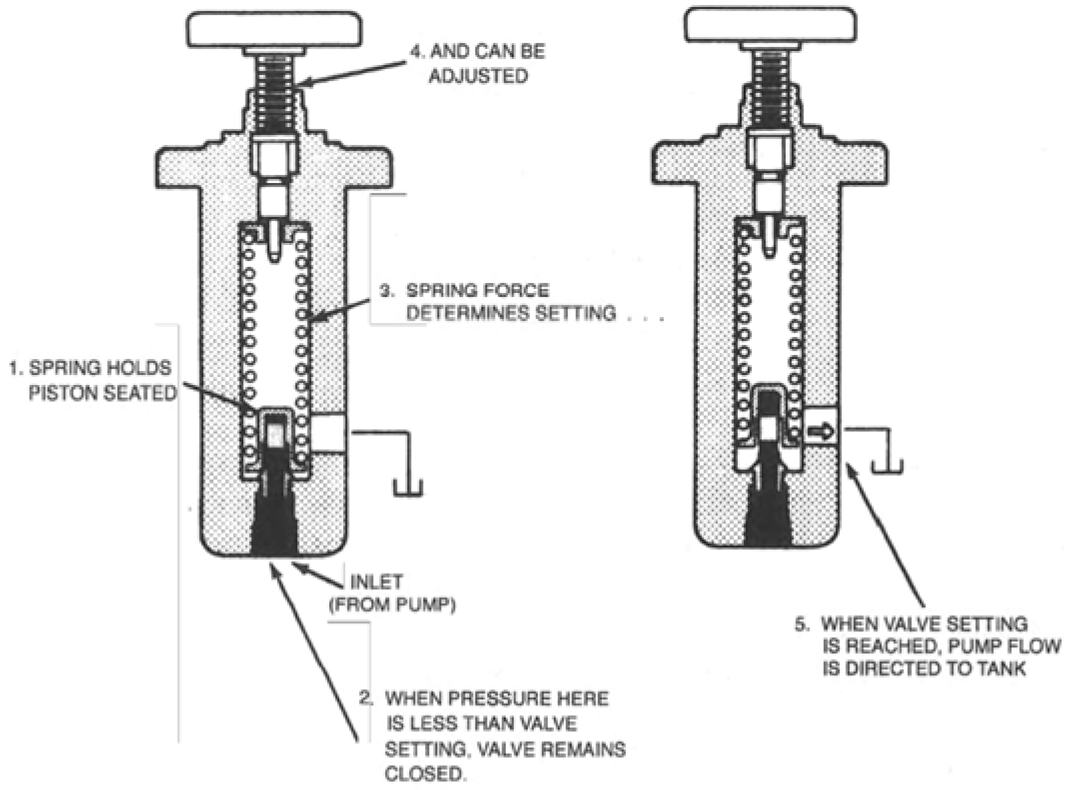


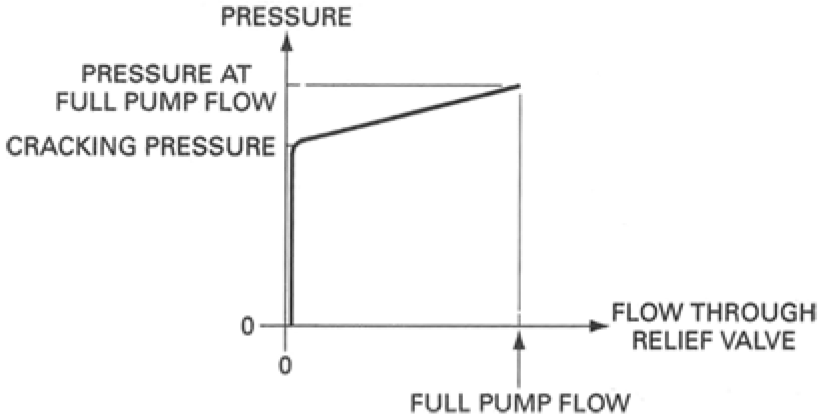
Application with a hydraulic pump

8.3 Pressure Relief Valve

The Pressure Relief is a normally non-passing valve. The setting is set through the adjustable screw which changes the pre-load on the spring holding the poppet closed.

As the pump pressure exceeds this spring pre-load, the poppet opens allowing oil to flow back to tank, thus limiting the maximum pressure in the system





8.3 Pressure Relief Valve

Example: A pressure relief valve has a pressure setting of 1000 psi. Compute the horsepower loss across this valve if it returns all the flow back to the tank from a 20-gpm pump.

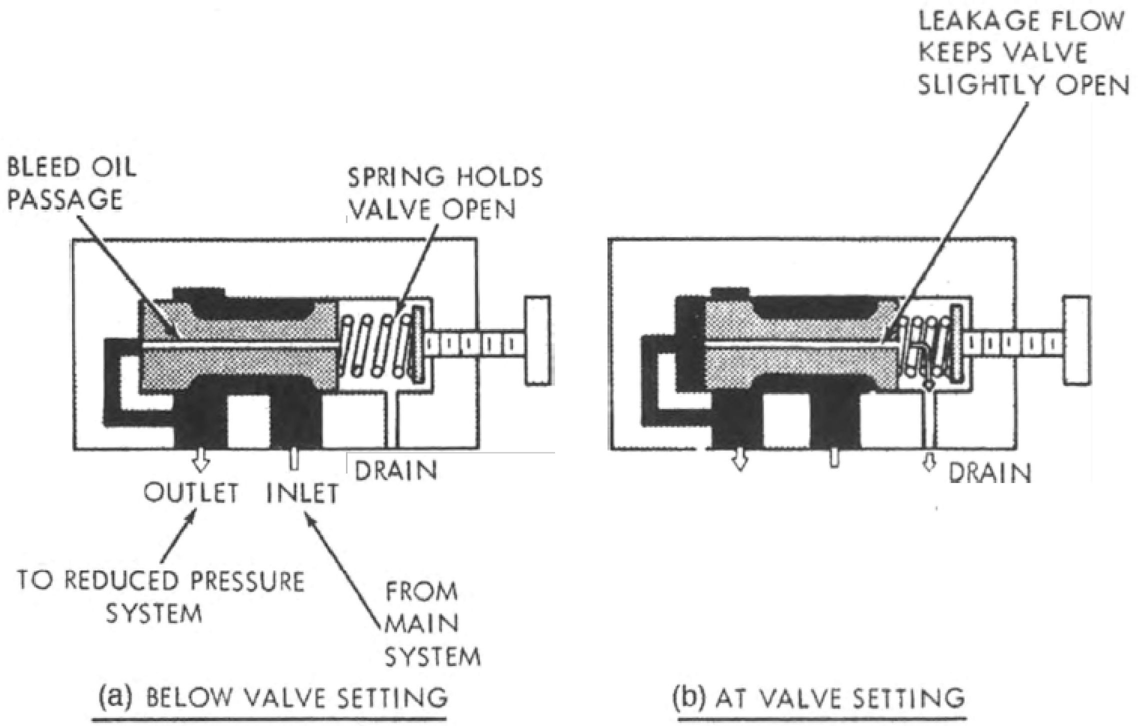
$$HP = \frac{pQ}{1714} = \frac{(1000)\,(20)}{1714} = 11.7 \text{ hp}$$

8.3 Pressure Reducing Valve

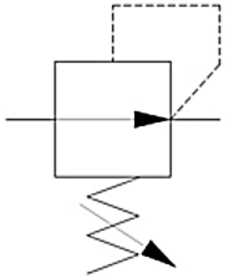
The Pressure Reducing Valve is a normally passing valve used to reduce the pressure in the part of the hydraulic system downstream from the valve.

This permits different pressures in different parts of the system, resulting in different forces being generated by different cylinders because of the different pressures.

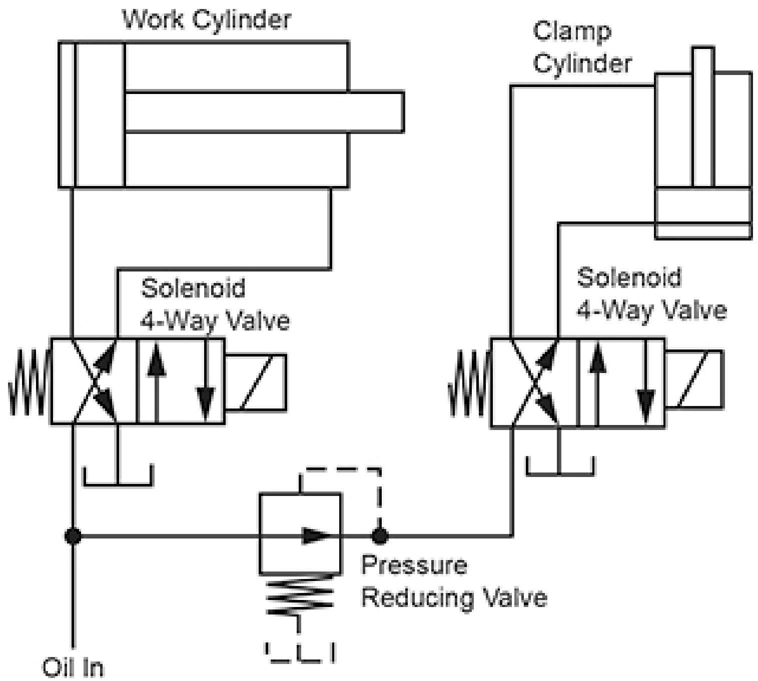
Pilot Pressure is sensed downstream of the valve and will close the valve once the set pressure is reached



8.3 Pressure Reducing Valve



Schematic Symbol*



Application with a Pressure Reducing Valve

https://www.womackmachine.com/engineering-toolbox/data-sheets/applications-for-pressure-reducing-valves/

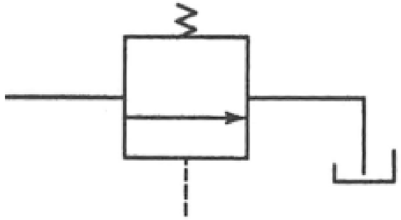
Work Cylinder operates at system pressure

Clamp Cylinder operates a reduced pressure set through the Pressure Reducing Valve

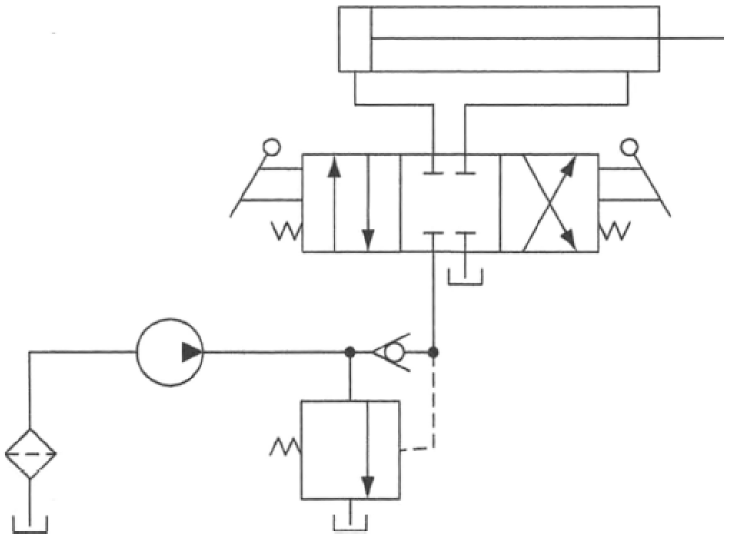
*the schematic in the text book incorrectly shows the pilot on the upstream line

8.3 Unloading Valve

The Unloading Valve operates like a Pressure Relief Valve, but permits the pump to operate at no-load once the desired system pressure is achieved.



Schematic Symbol



Application with an Unloading Valve

While the remote pilot pressure is high, the valve will open to allow the pump oil to flow freely to tank

8.3 Unloading Valve

Example: An unloading valve has a pressure setting of 1000 psi and is used to unload the pump. The pump discharge pressure (during unloading) is 25 psi. How much hydraulic horsepower is being wasted?

$$HP = \frac{pQ}{1714} = \frac{(25)\,(20)}{1714} = 0.29 \text{ hp}$$

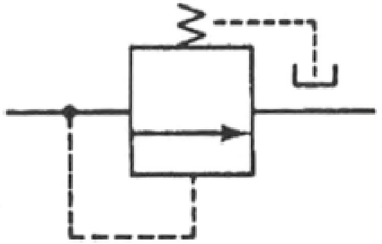
Compare this the HP lost using a Pressure Relief Valve (from earlier slide).

$$HP = \frac{pQ}{1714} = \frac{(1000)\,(20)}{1714} = 11.7 \text{ hp}$$

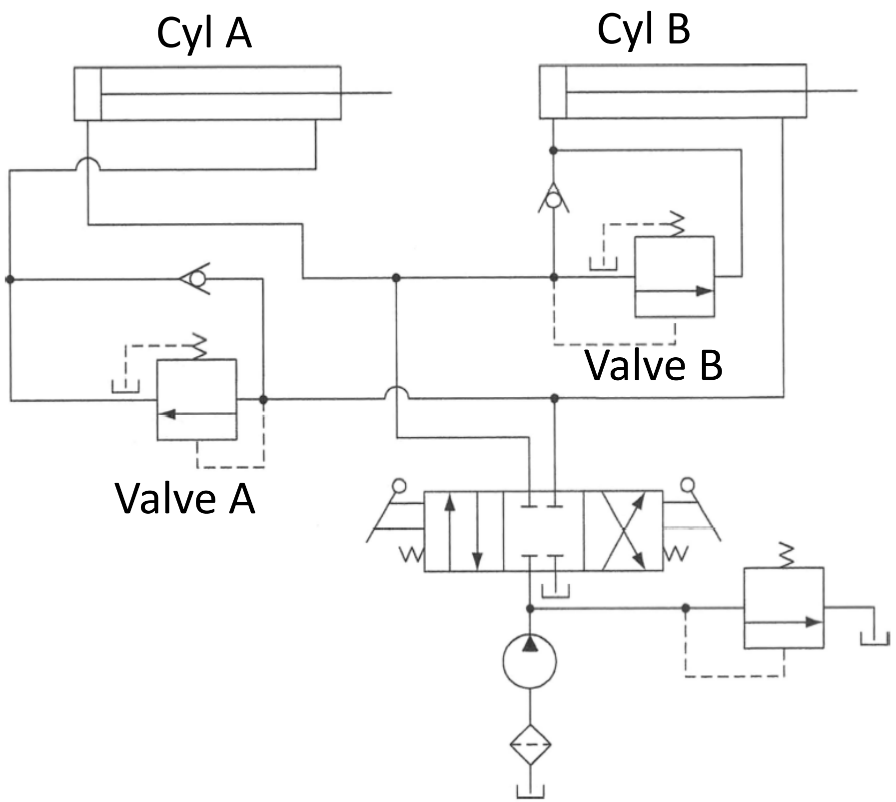
8.3 Sequence Valve

The Sequence Valve operates one part of a circuit after another part has completed.

It detects pilot pressure upstream and opens the valve once a set pressure is reached.



Schematic Symbol



Application with a Sequence Valve

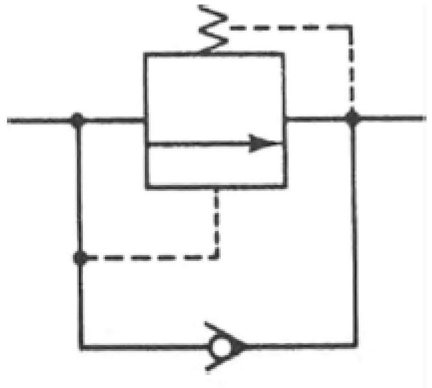
While *Cylinder A* is extending, the pressure on extension will be below the set point of *Valve B*.

Once extension is complete, the pressure will rise triggering *Valve B* top open and hence *Cylinder B* will then extend.

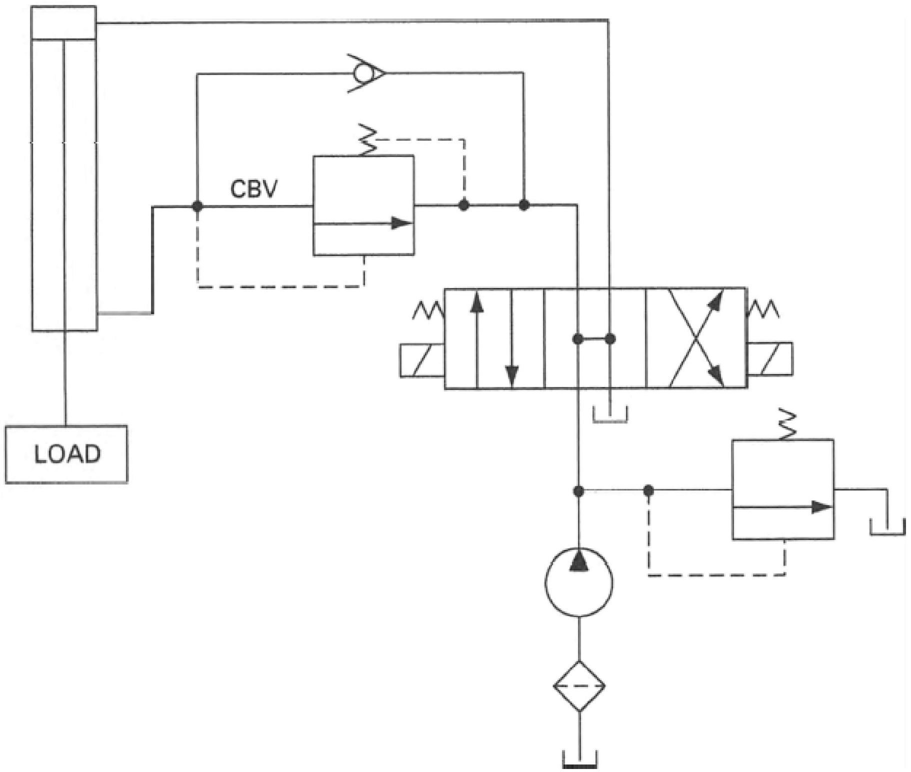
Similarly, once *Cylinder B* has retracted, *Valve A* will be triggered resulting in *Cylinder A* retraction.

8.3 CounterBalance Valve

The CounterBalance Valve is used to prevent runaway loads, for example when working with loads under gravity.



Schematic Symbol



Application with an Counter Balance

On extension, or hold (DCV center position), the cylinder will tend to runaway under gravity.

The CBV will remain closed preventing runaway, until input (upstream) pilot pressure is high enough as a result of the extension being commanded.

On retraction, the check-valve permits full flow to cylinder.

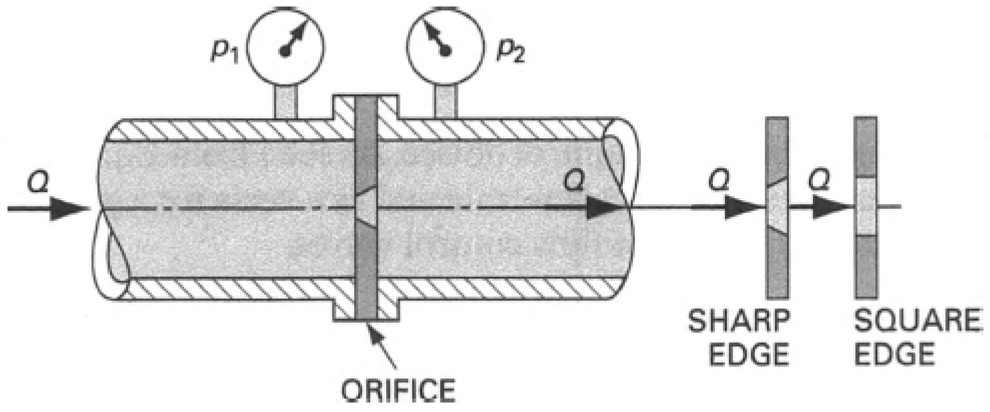
Flow Control Valve

https://ph.parker.com/us/en/in-line-flow-control-valve-f-series

8.4 Flow Control Valve

Flow control valves are used to regulate (or meter) the flow rate of hydraulic fluid in a circuit. The result is speed control of cylinders or motors.

They operate by forcing the oil through an orifice in a pipe, thus reducing the flow rate, and consequently producing a pressure drop across the orifice

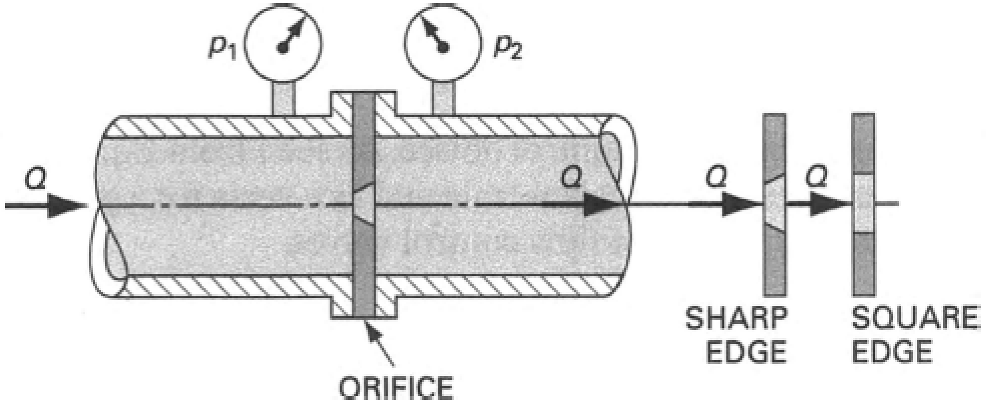


$$Q = 38.1\, C A \sqrt{\frac{\Delta p}{SG}}$$

Q = flow rate (gpm)
C = flow coefficient
C = 0.80 for sharp-edged
C = 0.60 for square-edged orifice
A = area of orifice opening (in^2)
$\Delta p = P_1 \sim P_2$ - pressure drop across orifice (psi)
SG = specific gravity of flowing fluid.

8.4 Flow Control Valve

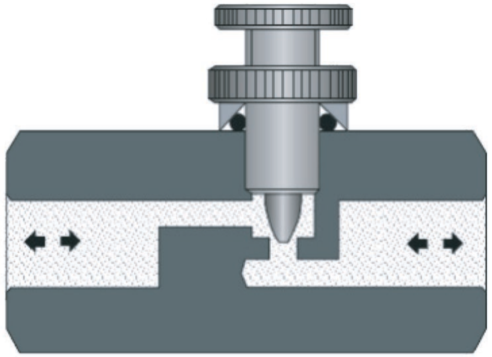
Example: The pressure drop across the sharp-edged orifice is 100 psi. The orifice has a 1-in diameter, and the fluid has a specific gravity of 0.9. Find the flow rate in units of gpm.



$$Q = (38.1)(0.80)\left(\frac{\pi}{4} \times 1^2\right) \times \sqrt{\frac{100}{0.9}} = 252 \text{ gpm}$$

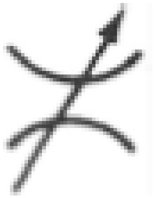
8.4 Flow Control Valve

Adjustable orifices provide greater control of actuator speed.
Needle valves are most common.



Cross Section

https://fluidpowerjournal.com/understand-flow-control-valves/



Schematic Symbol

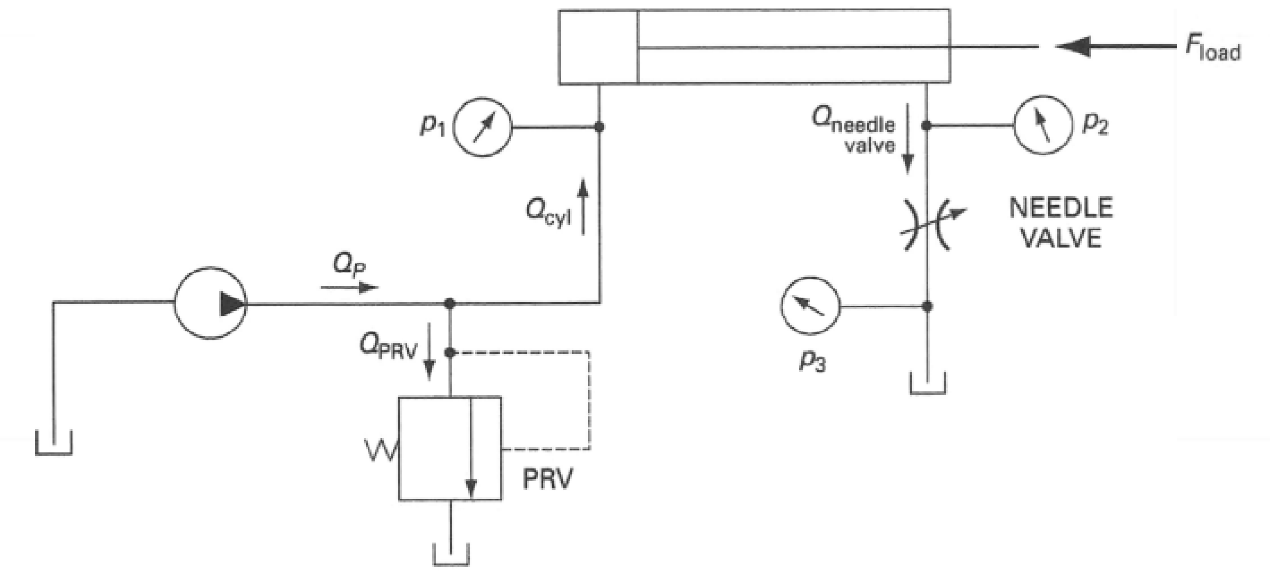
$$Q = C_v \sqrt{\frac{\Delta p}{SG}}$$

Q = flow rate (gpm)
Cv = capacity coefficient (gpm $/\sqrt{psi}$)
provided by manufacturer
A = area of orifice opening (in^2)
$\Delta p = P_1 \sim P_2$ - pressure drop across valve (psi)
SG = specific gravity of flowing fluid.

8.4 Flow Control Valve

A flow control valve is installed in the retraction side of the cylinder to control the speed of extension. This is a ‘meter-out’ configuration.

As the cylinder is extended, the cylinder out flow ($Q_{needle\ valve}$) is restricted by the FCV and creates a back pressure P_2 on the rod end of the cylinder resulting in P_1 increasing. When P_1 exceeds the PRV setting, part of the pump flow (Q_P)empties to tank (Q_{PRV})resulting in less flow to the cylinder (Q_{cyl}), hence slower extension speed.



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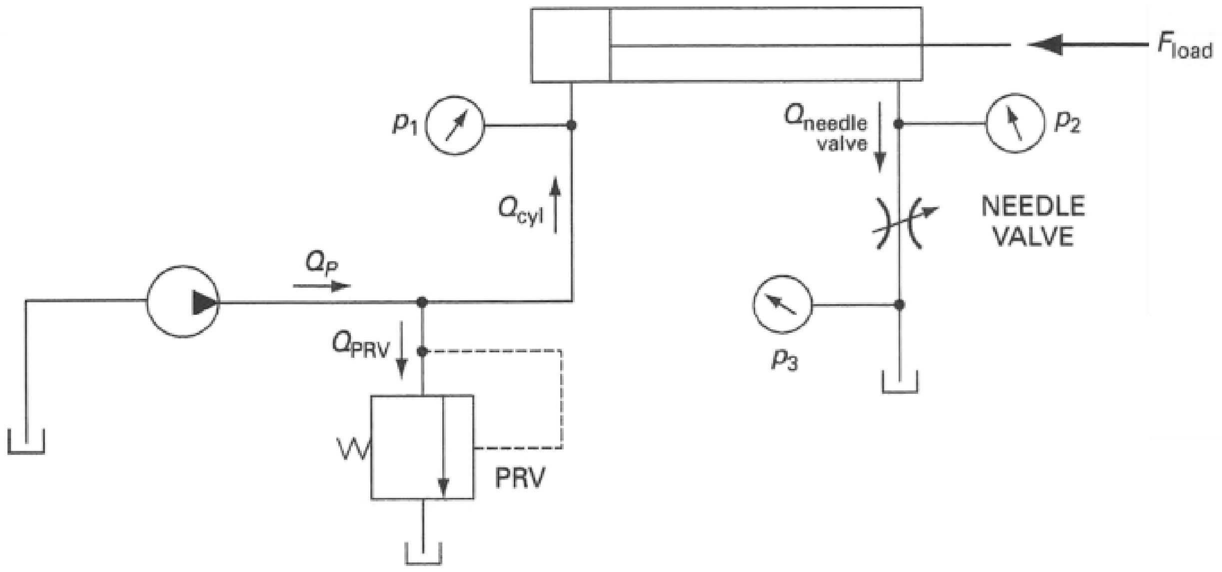
8.4 Flow Control Valve

Example: A needle valve is used to control the extending speed of a hydraulic cylinder. The needle valve is placed in the outlet line of the hydraulic cylinder, as shown
The following data are given:
1. Desired cylinder speed = 10 in/s
2. Cylinder piston diameter = 2 in (area = 3.14 in^2)
3. Cylinder rod diameter = 1 in (area = 0.79 in^2)
4. Cylinder load = 1000 lb
5. Specific gravity of oil = 0.90
6. Pressure relief valve setting (PRV setting) = 500 psi
Determine the required capacity coefficient of the needle valve.



8.4 Flow Control Valve

First, we solve for the rod end pressure P_2 that causes the blank end pressure P_1 to equal the PRV setting. This is done by summing forces on the hydraulic cylinder.

$$p_1 A_1 - F_{\text{load}} = p_2 A_2 \qquad \begin{aligned} A_1 &= \text{piston area,} \\ A_2 &= \text{piston area minus rod area.} \end{aligned}$$

$$500 \text{ lb/in}^2 \times 3.14 \text{ in}^2 - 1000 \text{ lb} = p_2(3.14 - 0.79)\text{in}^2$$

$$p_2 = 243 \text{ psi}$$

Next, we calculate the flow rate through the needle valve based on the desired hydraulic cylinder speed.

$$Q = A_2 v_{\text{cylinder}} = 2.35 \text{ in}^2 \times 10 \text{ in/s} = 23.5 \text{ in}^3\text{/s}$$

$$= 23.5 \text{ in}^3\text{/s} \times \frac{1 \text{ gal}}{231 \text{ in}^3} \times \frac{60 \text{ s}}{1 \text{ min}} = 6.10 \text{ gpm}$$

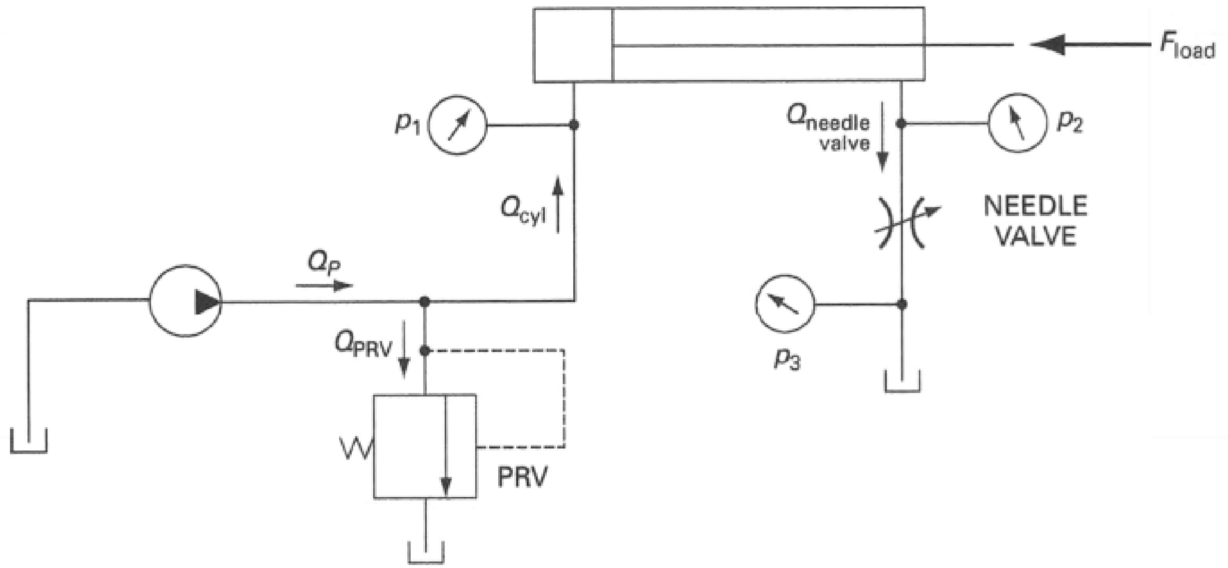
Since the discharge from the needle valve flows directly to the oil tank, pressure P_3 = 0. Thus, P_2 equals the pressure drop across the needle valve and we can solve for Cv

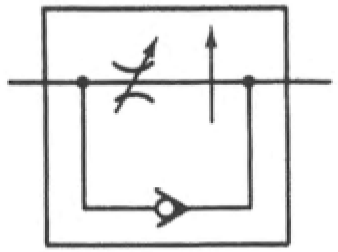
$$C_v = \frac{Q}{\sqrt{\Delta p/SG}} = \frac{6.10}{\sqrt{243/0.90}} = 0.37 \text{ gpm}/\sqrt{\text{psi}}$$

8.4 Flow Control Valve

If F_{load} is not constant, then Δp across the FCV changes, and as a result Q changes, and hence the speed of the cylinder changes. This is true for **<u>Non-Pressure-Compensated Valves</u>**

Pressure-Compensated Valves *automatically* adjust the orifice and hence flow rate in response to changing delta-p across the valve to maintain a constant flow rate





Schematic Symbol

A check valve allows non-metered flow in the opposite direction

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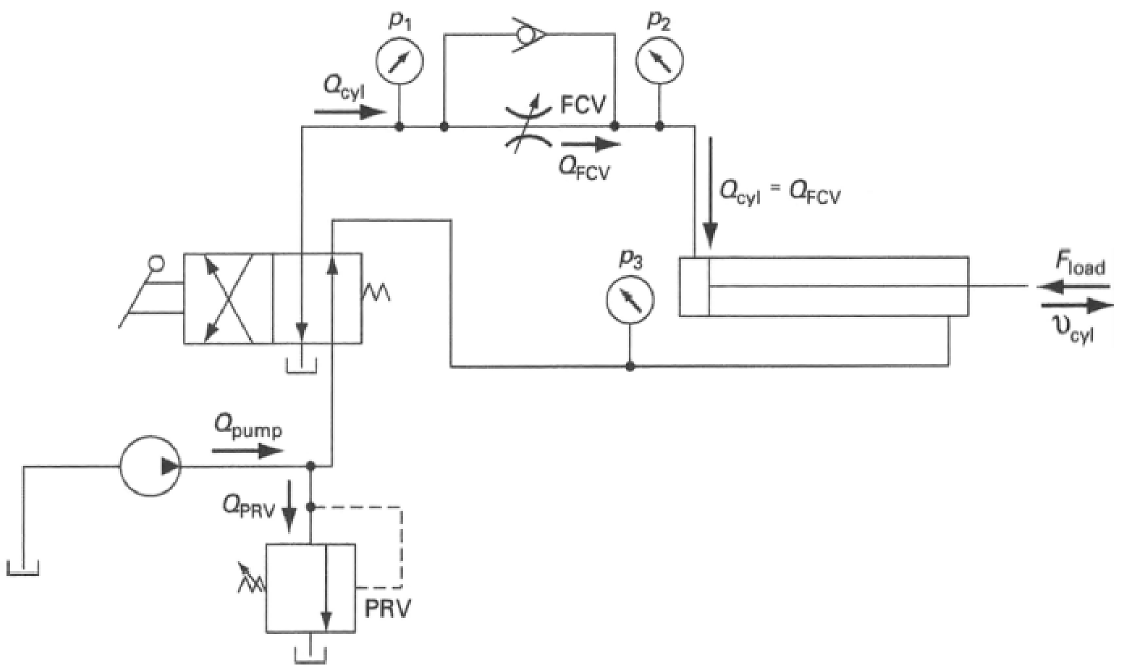
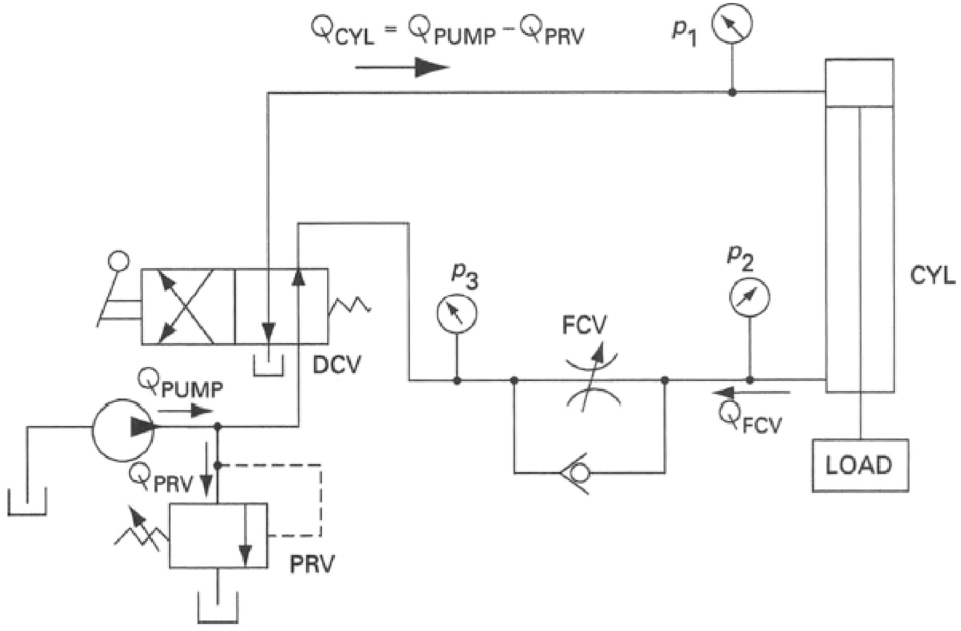
8.2 Flow Control Valve – Meter in/out





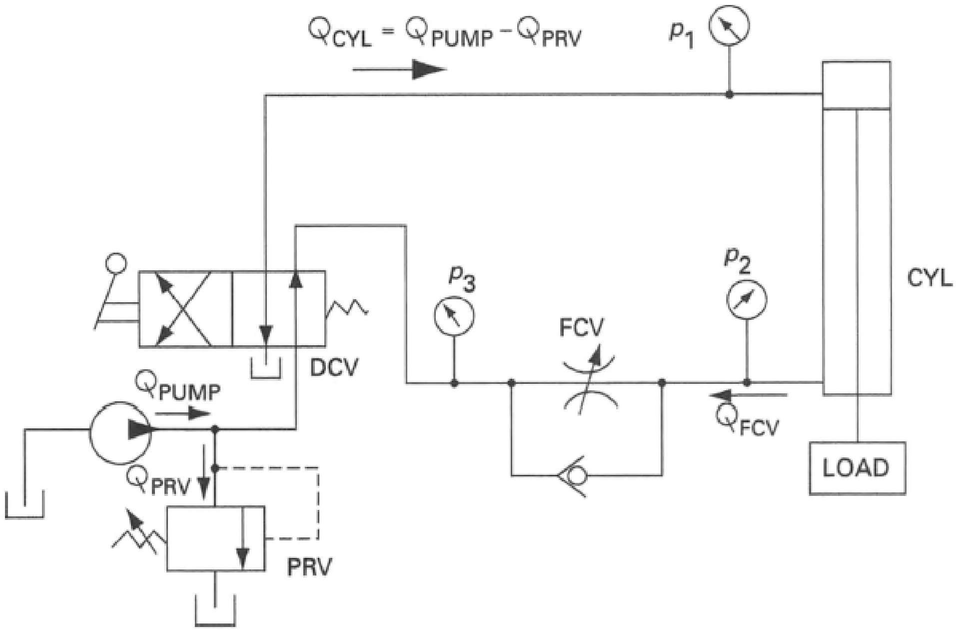
A meter-in circuit is used when the external load opposes the extension direction

A meter-out circuit is used when the external load opposes the retraction direction, or for example when a vertical cylinder is holding up a load against gravity.

Caution: will increase pressure at rod-end of cylinder, and high pressure drop across PCV resulting in increased oil temperature and component failure

8.2 Flow Control Valve – Meter in/out

Consider the meter-out configuration shown, with the following parameters
-system pressure is 1500 psi
-cylinder bore is 3”
-cylinder rod is 2”
If the FCV is completely closed, what will P_2 read?



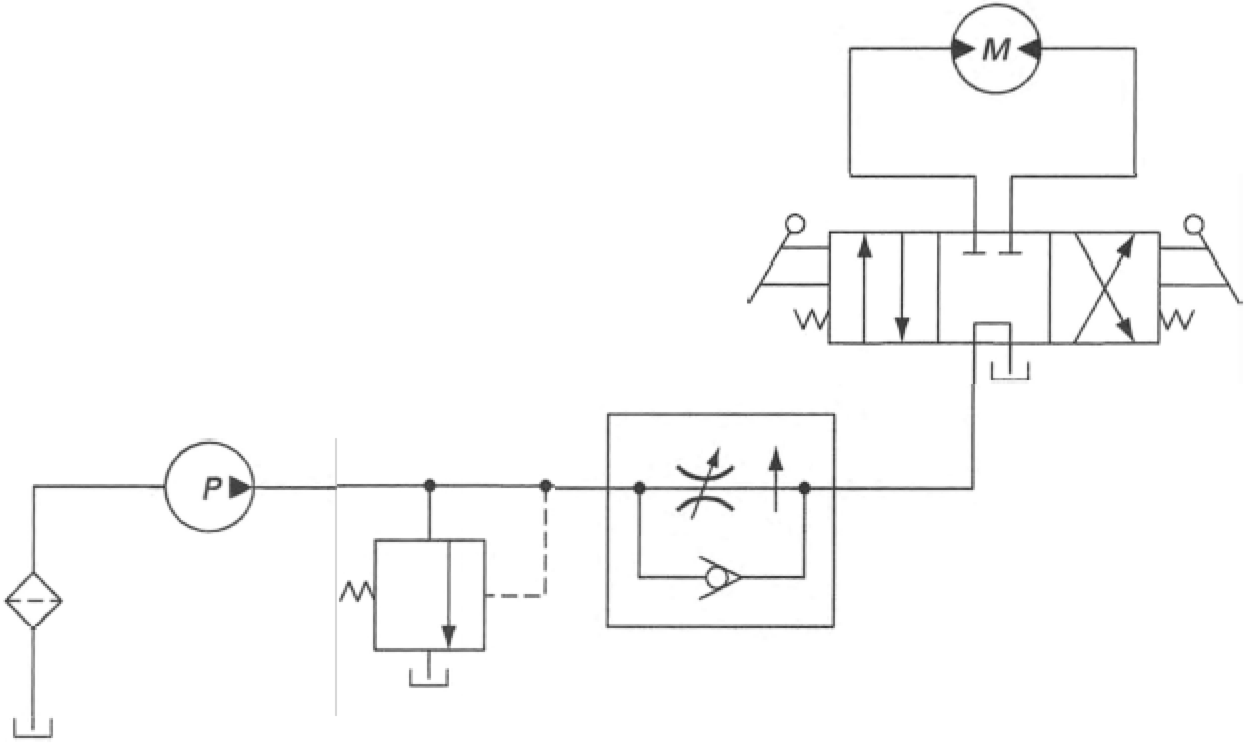
First, using system pressure P_1 find the force being applied to the piston, then using that force find the pressure in the rod side P_2.

$$F_{piston} = p_1 \times Ap$$
$$F_{piston} = p_1 \times \frac{\pi}{4} D^2$$
$$F_{piston} = 1500\, psi \times \frac{\pi}{4} 3''^2$$
$$F_{piston} = 10603\, lbs$$

$$F_{piston} = p_2 \times A_r$$
$$10603\, lbs = p_2 \times \frac{\pi}{4}\left(D_p^2 - D_r^2\right)$$
$$p_2 = 10603\, lbs \div \frac{\pi}{4}(3in^2 - 2in^2)$$
$$p_2 = 2700\, lbs$$

Note that P2 is almost twice the system pressure, and care must be exercised when using meter-out systems

8.2 Flow Control Valve – Meter in/out



Speed control of a hydraulic motor using metering

Chapter Reading

Chapter 8

8.5-8.8