Chapter 5: Pressure Valves

Pressure valves are introduced at this stage because the following sections require a basic knowledge of their operation.

Valves play an integral part in any hydraulic circuit. They fall into four main categories (a) pressure control valves (b) flow control valves (c) directional control valves (d) servo valves. This section shall consider pressure control valves with emphasis placed on operation and application.

5.1   Pressure Control/Limiting Valves

- These are used to maintain desired pressure levels in various parts of a circuit.
- There are two basic categories: (1) those that divert high pressure to a low pressure area or (2) those that restrict flow to another area. Valves that divert flow include: safety, relief, counterbalance, sequence, and unloading. Valve that restrict flow are of the reducing type.

5.1.1 Safety Valve

- Usually a poppet type two way valve (flow or no flow) intended to release fluid to a secondary area when fluid pressure approaches the opening pressure of the valve.
- Protects piping and equipment from excessive pressure.
- Must be reliable.
- Usually set at 25% higher than maximum pressure.

5.1.2 Relief Valve

- A normally closed valve usually connecting a pressure line to the reservoir.
- Limits pumps output pressure by diverting some or all of the flow back to tank.
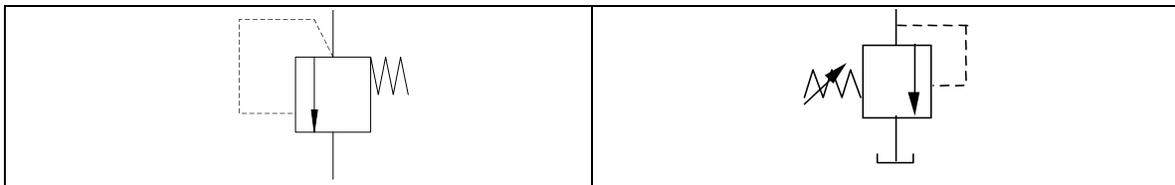

Figure 5.1 Relief Valve symbols

5.1.2(a) Simple Relief Valve

- Called a direct acting relief valve consisting of a ball or poppet biased by a spring.

When line pressure creates a force on the ball or poppet which exceeds the spring pretension, the poppet opens and fluid flows to tank as long as $P_{setting}$ is exceeded.
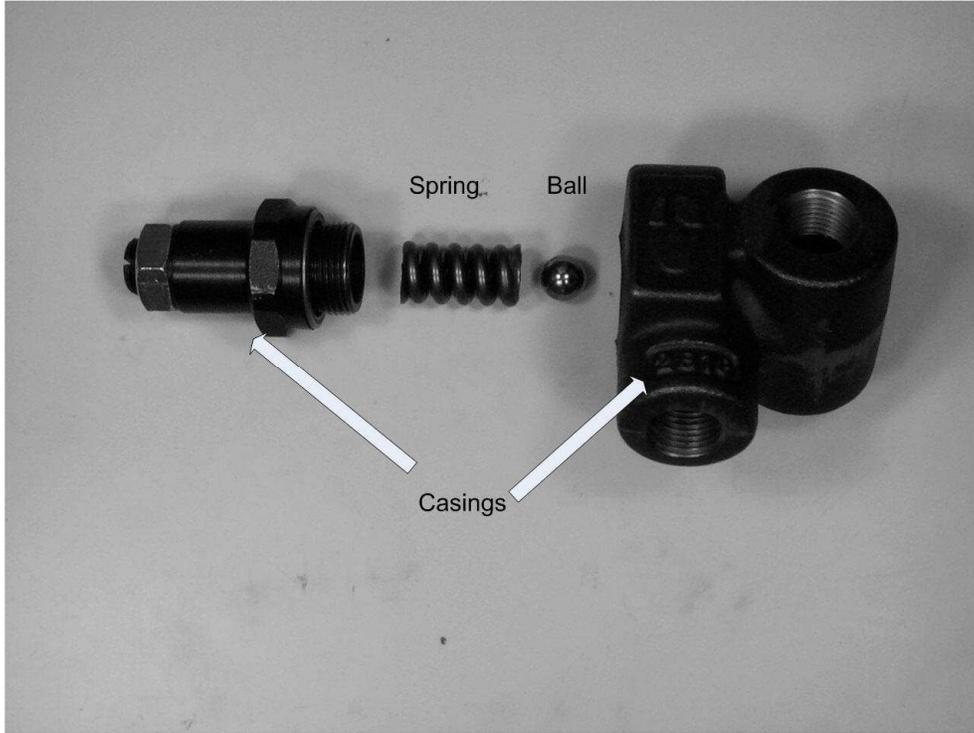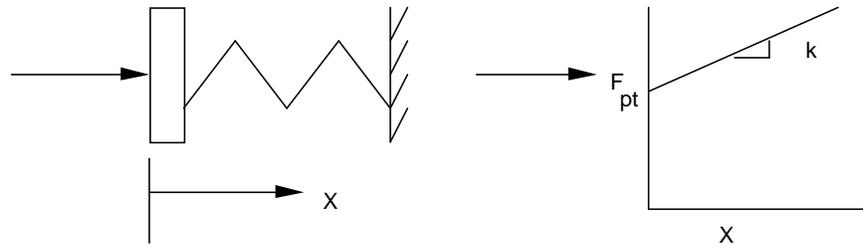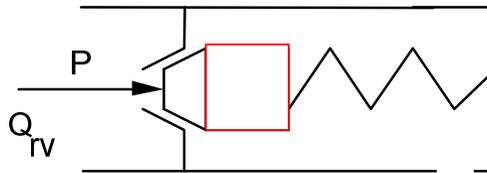

Figure 5.2 Basic ball type relief valve

$$F = K_s x + F_{pt} \qquad\qquad F = K_s x + F_{pt}$$

P_s

$P_s A < F_{pt}$

P_s

$P_s A > F_{pt} + K_s x$
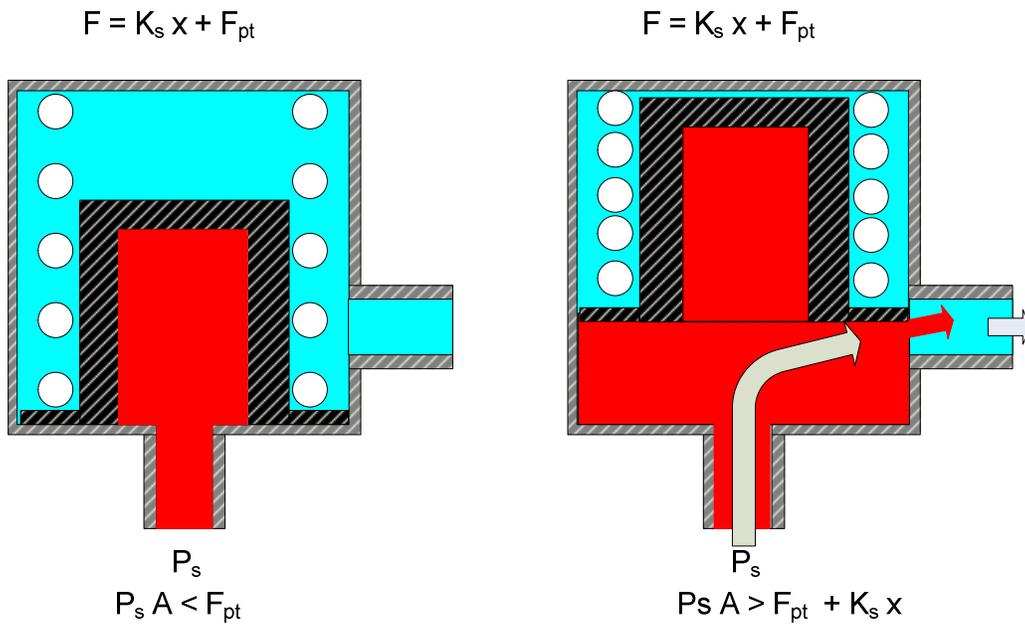
Figure 5.3   Operation of a single stage relief valve

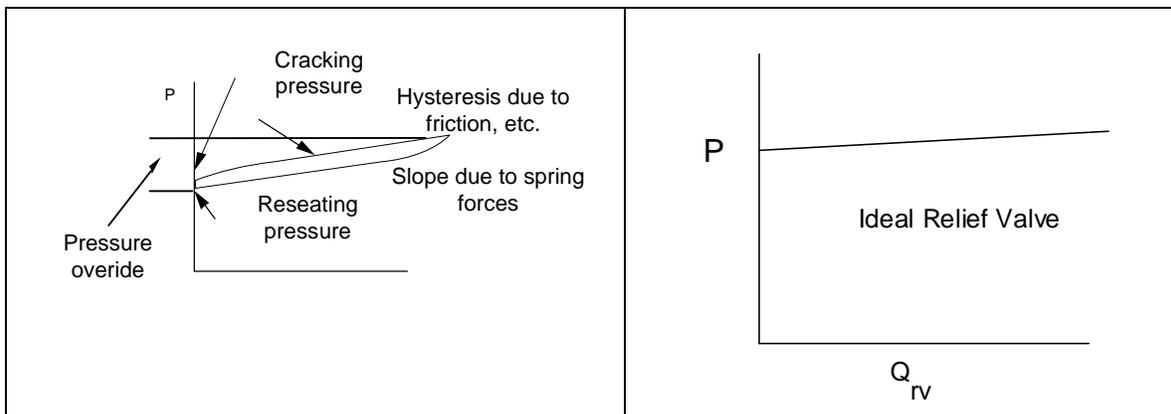### 5.1.3 Basic operating principal: Force

Figure 5.4 Operation

5.1.4 Basic operating principal: hydraulic

The pressure at which the valve opens is called <u>cracking pressure</u>.
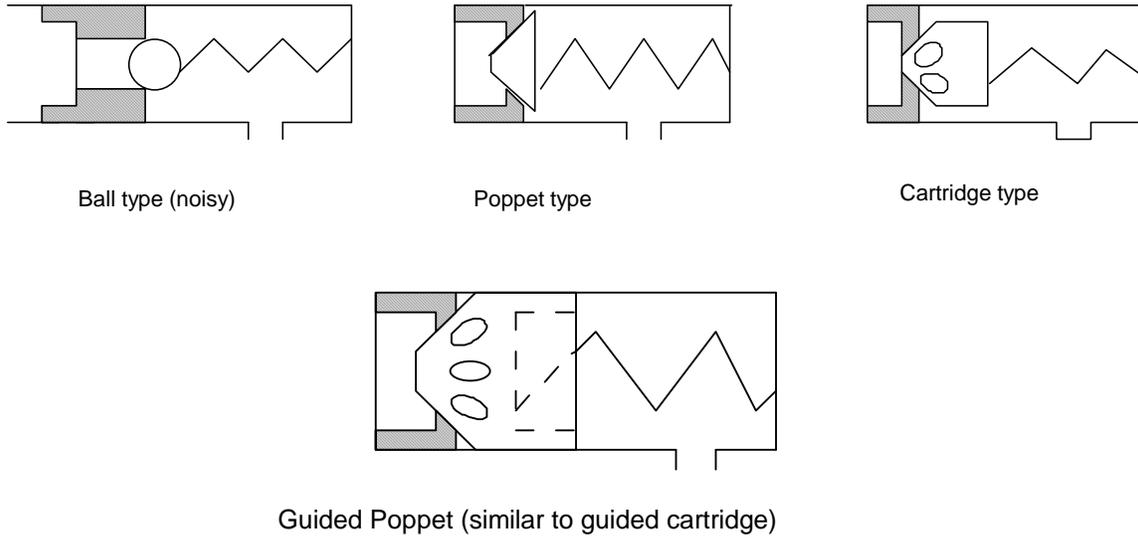

Figure 5.4 Actual and ideal relief valve characteristics for a single stage relief valve.

5.1.5 Types of relief valve inserts
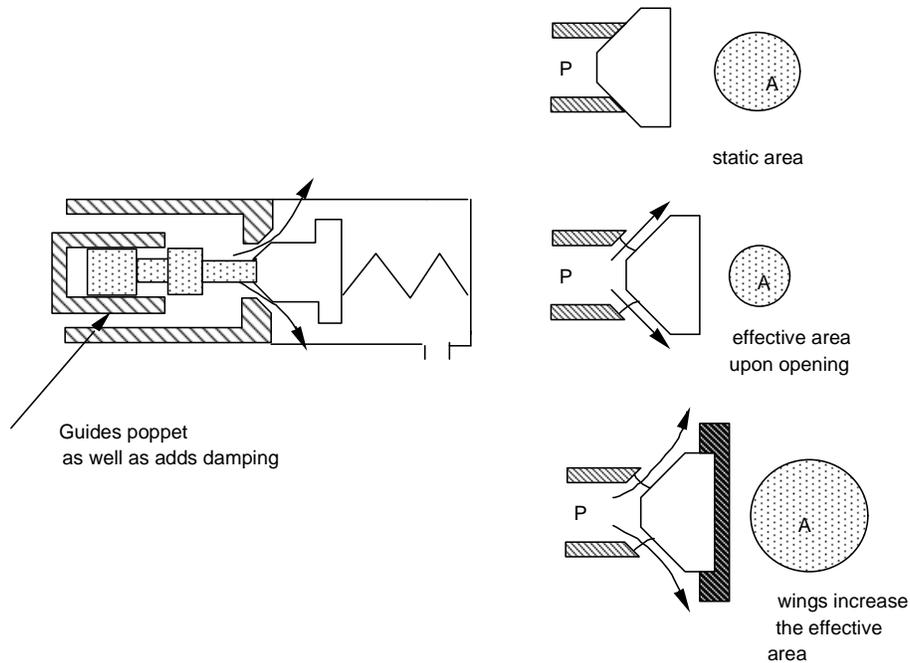
Direct Acting
- cheap
- large pressure over-ride and hysteresis

- noisy

Ball type (noisy)   Poppet type   Cartridge type

Guided Poppet (similar to guided cartridge)

Figure 5.5 Insert types of relief valves

Guided poppets tend to be more stable in operation. This is illustrated in Figure 5.6.

static area

effective area
upon opening

Guides poppet
as well as adds damping

wings increase
the effective
area

**Figure 5.6 Guided poppet relief valve**

5.1.2(b) Compound Relief Valve
- Operates in two stages
- Designed to give flatter P-Q curves
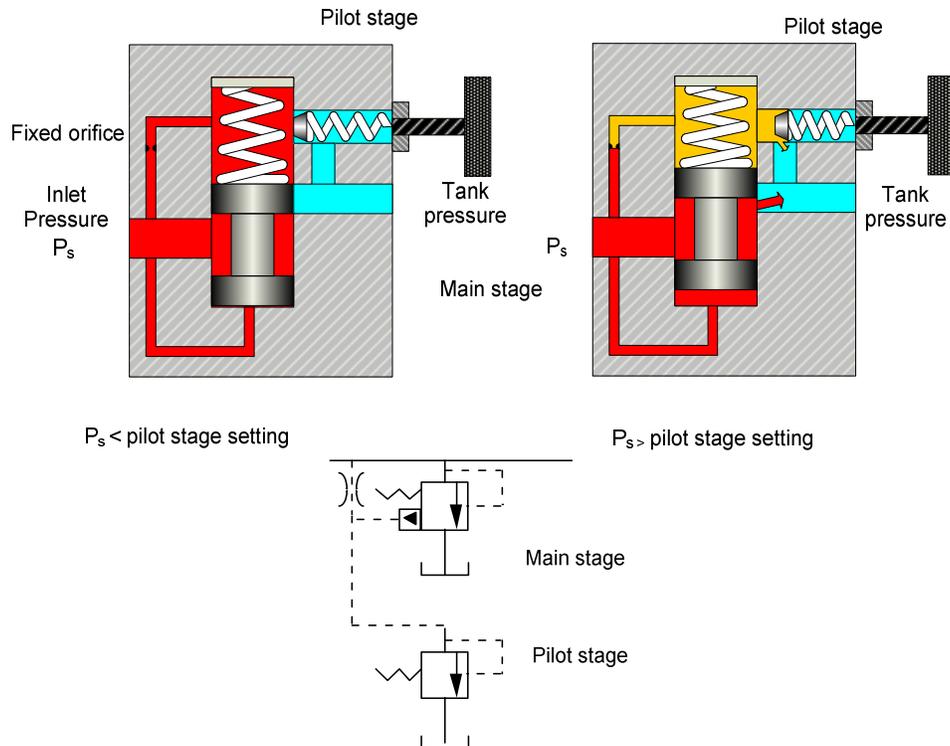
Figure 5.5 Two stage relief valve and composite symbol

OPERATION: High pressure occupies main cavity, and control chamber (via orifice connection). The poppet and spring (smaller) is a direct acting R.V. When P_s exceeds the pilot poppet spring force, it opens. Fluid from the control chamber flows to tank. Because of the orifice, the pressure in the inlet rises higher than in the control chamber; therefore, a ΔP differential exists across the main spool causing it to move and, hence, port fluid to tank. A photo of a two stage valves is shown in Figure 5.6
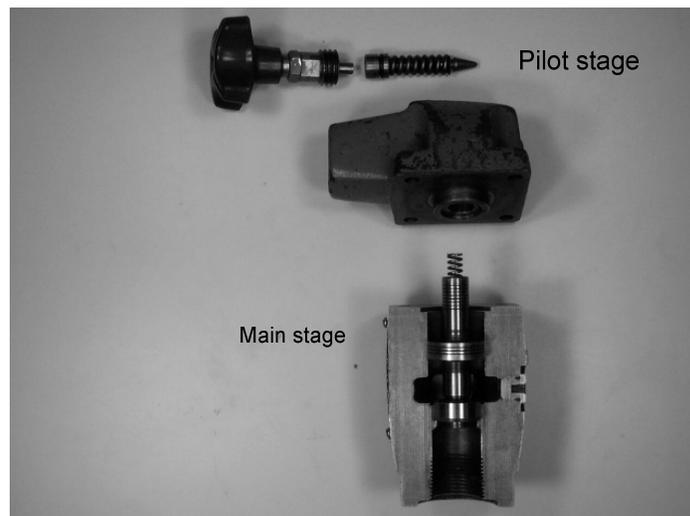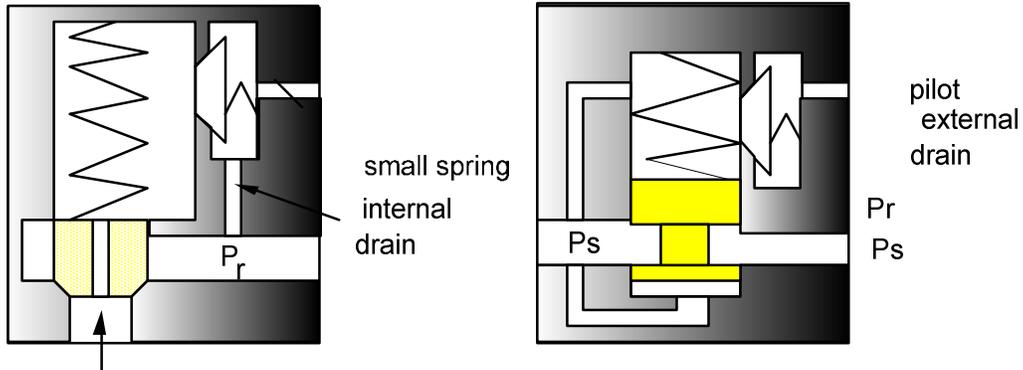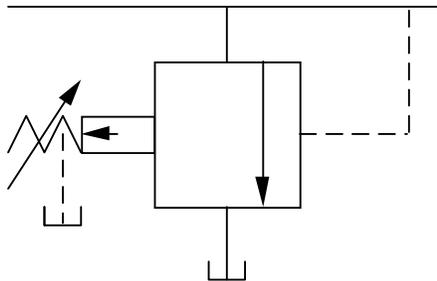

Figure 5.6 Two stage Relief valves

The vent of these valves can be connected to a control pressure external to the valve at a remote location.

5.2.3 Types of Pilot operated Relief valves inserts

cartridge design, piston, poppet

The symbol (composite) for a pilot relief valve with external drain is:

Symbol for pilot Relief Valve
with external drain

Figure 5.7 Two stage relief valves with cartridge and piston inserts and composite diagram

5.1.2(c) Unloading Valve

-   Valve which allows pressure to build up to an adjustable pressure, then bypasses flow as long as a remote source maintains the preset pressure on the pilot port
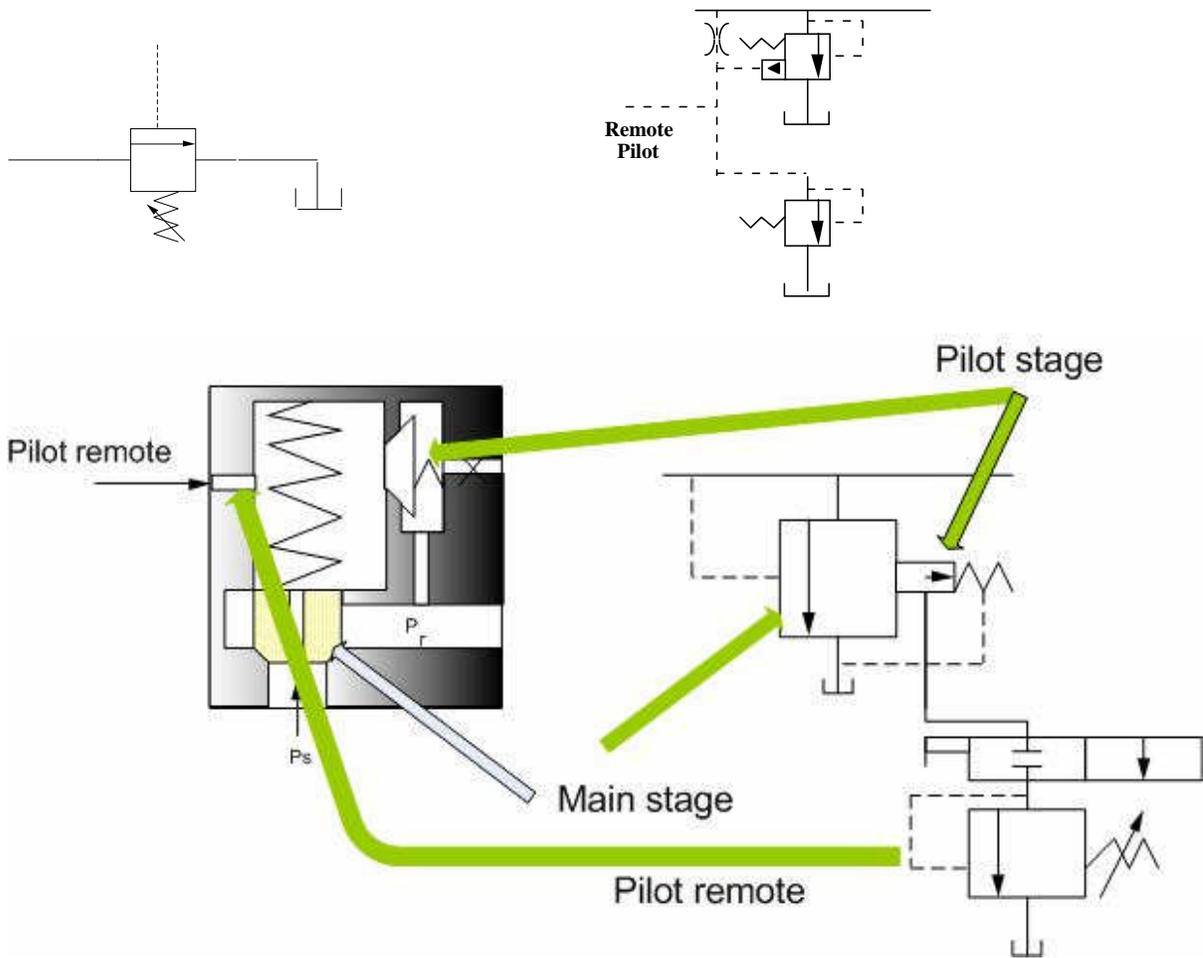
Figure 5.7 Remote piloted relief valve (unloading) and symbols
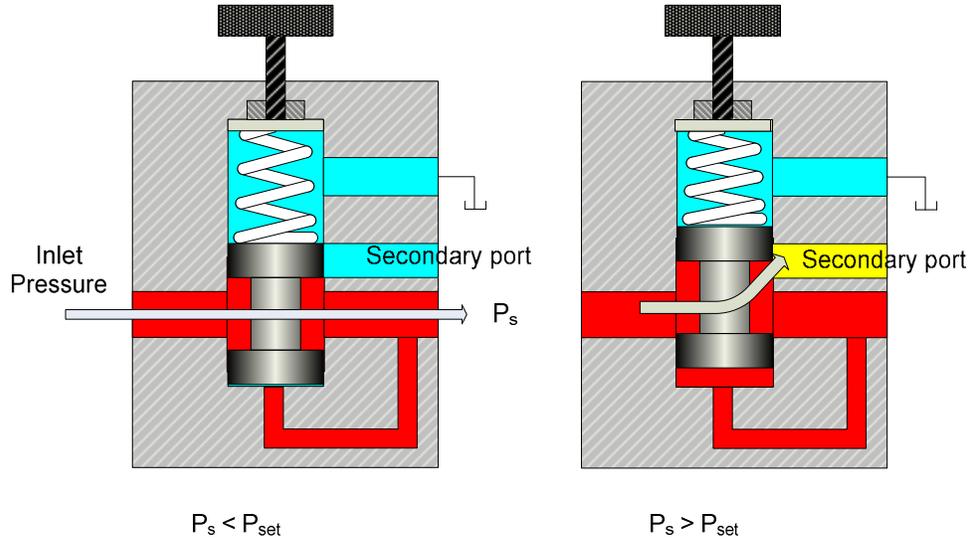
5.1.2(d) Sequence Valve

Valve which diverts flow to more than one portion of a circuit in sequence. An internal check valve can be included for return flow.
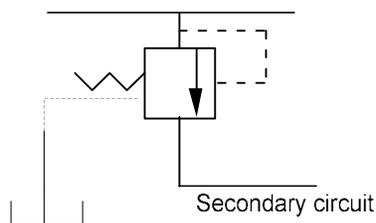
Operation (reference Figure 5.8)

When the line pressure is less than the preset pressure on the spring (P_{set}), the valve is closed and no flow is passed to the secondary circuit. When P_s is greater than P_{set}, the spool moves up (Figure 5.8) and ports fluid to the second circuit. In this valve, the

main line flow is through the valve. This is not the case for other configurations because of losses that can be incurred inside the valve.

Ps < Pset   Ps > Pset

Figure 5.8 Sequence Valve

NOTE: Because the secondary port is at some pressure other than tank, the outlet side of the pilot valve MUST BE VENTED TO TANK. This is very important!!!!!
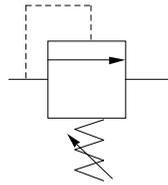
Consider the sequence circuit shown in Figure 5.9
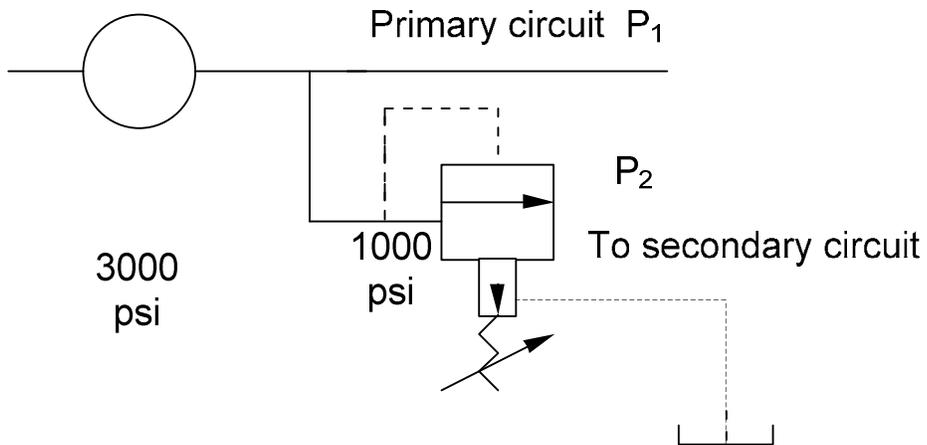
Figure 5.9 Sequence circuit

The sequence valve opens when $P_1 = P_{setting}$, 1000 psi in this case

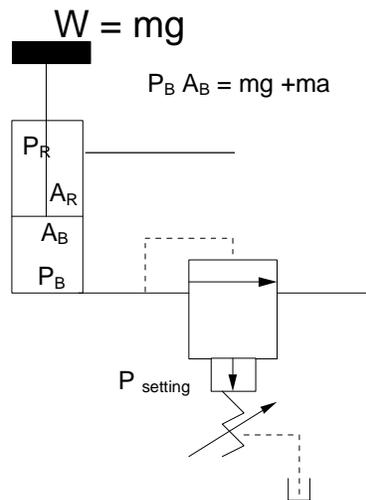## 5.1.2(e) Counterbalance Valves (Figure 5.10)

- Valve which maintains resistance against flow in one direction.
- Used in circuits to prevent cylinders (vertical) from falling because of gravity.
- Is an internal sequence valve with appropriate valve porting to load.
- These valves are often referred to as <u>holding valves</u>.
- Their prime function is to provide a "back resistance" in the presence of "runaway loads" or to hold a load in place until a certain pressure.

Inlet Pressure P_s

P_s

$P_s <$ counter balance pilot stage setting

$P_s >$ counter balance pilot stage setting
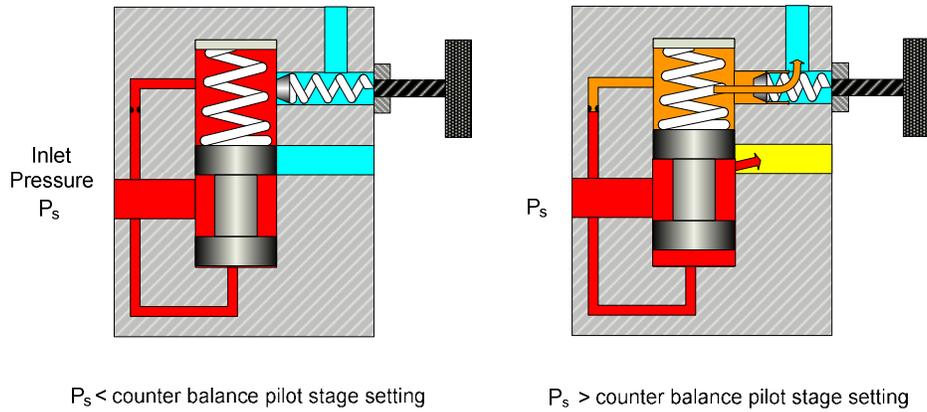
Figure 5.10 Counterbalance valve

Consider the following circuit (Figure 5.11).

$W = mg$

$P_B A_B = mg + ma$

P_R

A_R

A_B

P_B

$P_{setting}$

Figure 5. 11 Counterbalance valve example.

Consider when $P_R = 0$. If $P_{setting} = P_B$, then an exact force balance exists.

The weight can be considered as a "resistive" system rather than a "run-away" one. In order to move the load down, we must first push it down by applying fluid to the rod end. Thus $PR \neq 0$.

The equation of motion is thus (assuming down is positive):

$$P_R A_R - P_B A_B + mg = ma, \qquad \text{But } P_B A_B = mg$$

$$\text{Therefore,} \qquad P_R A_R = ma$$

Thus the only pressure we need is that to overcome inertial effects. In reality, this is not the case. There are losses across the valve as well as friction terms in the load actuator. This, this pressure P_R can be different but the example does serve to show how a counterbalance valve can be used to your advantage.

Consider the following situation depicted in Figure 5.12. In position 1, the actuator "sees" a resistive system. In position 2, it sees a run-away system. This type of system is called "over centre". How do we handle the situation when the load passes over centre?
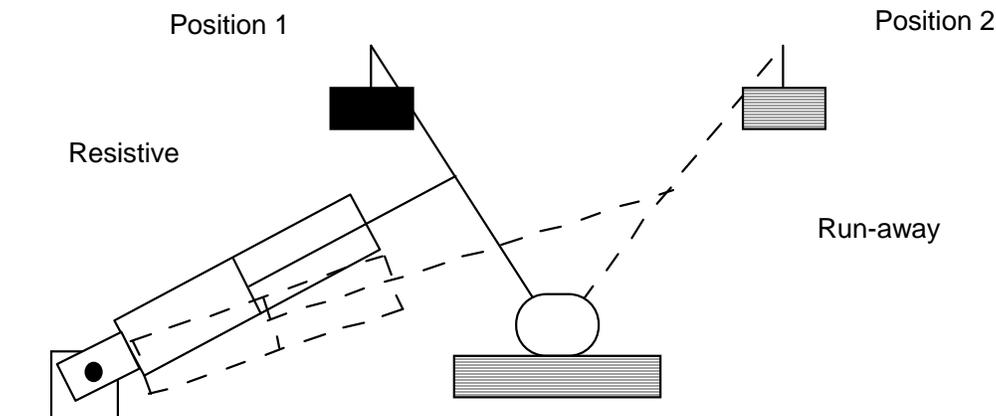

Figure 5.12 Cross-over loading system

 Solution: We make use of a pilot operated CBV as illustrated in Figure 5.13

In this type of valve, we port the upstream pressure to one side of the pilot valve of a two stage counterbalance balance valve. Consider Figures 5.13 and 5.14.
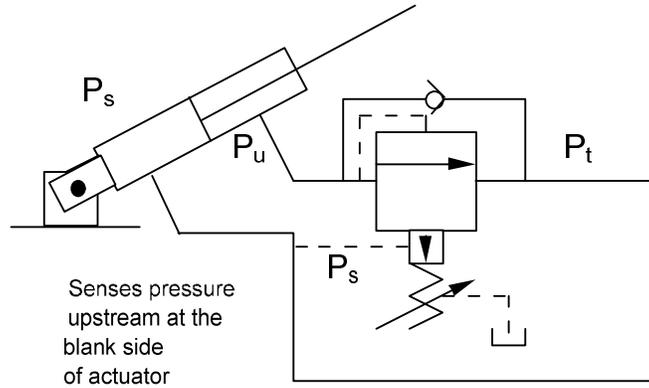
Figure 5.13 CBV example using a pilot line

Figure 5.14   Pilot operated counterbalance valve(a)

Figure 5.14   Pilot operated counterbalance valve(b)
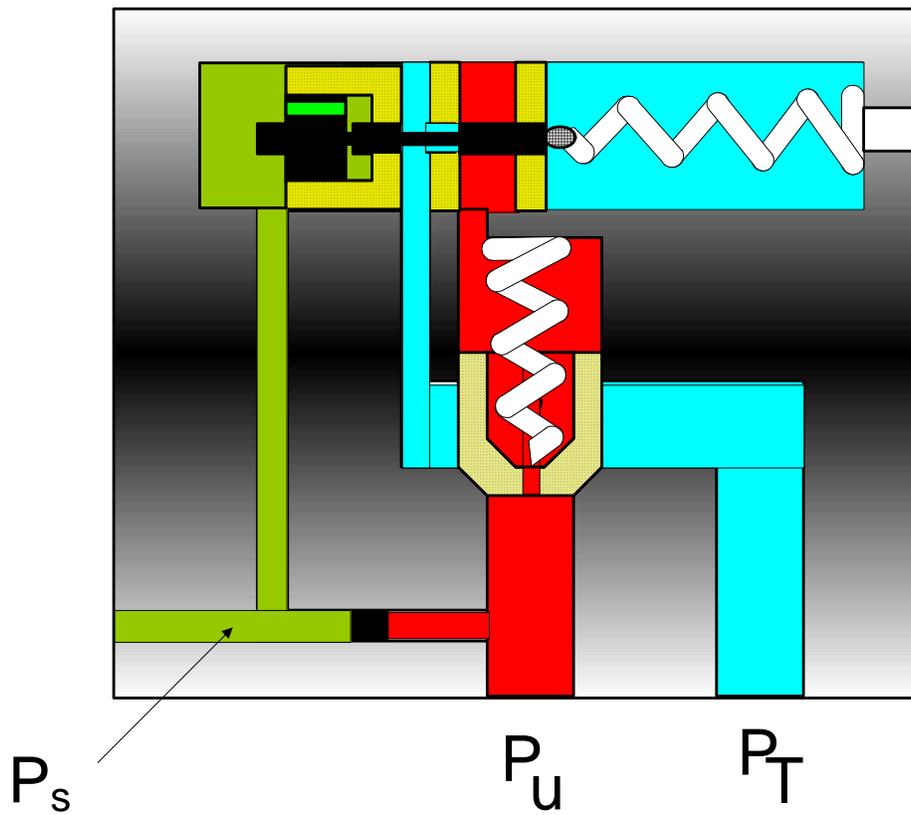
**Figure 5.14   Pilot operated counterbalance valve(c)**

Consider Figures 5.13 and 14(a). When P_s is less than 6.9MPa (for this example), the pilot stage is closed as shown in (a). The line is blocked and no flow passes through the main stage of the counterbalance valve. This is the case when there is little pressure upstream of the actuator, a situation which can occur when the load is in a runaway condition. Because there is no flow through the CBV, the pressure builds up in the lines between the actuator and the CBV. This means that pressure will increase upstream to the actuator because the resistance has increased. As a result, P_s increases which means that the pilot line pressure increases which forces the pilot spool to move to s slightly one position as shown in Figure 5.14 (b). At this point fluid is ported to tank in the chamber above the cartridge valve. The pressure drop across the cartridge increases which forces the cartridge to lift off its seal. Fluid is now ported to tank as illustrated. Under these conditions, the main cartridge is partially opened and acts as a metering valve. Flow is restricted.

If the pressure Ps is very high, then the pilot valve is fully opened and the cartridge is also fully opened. There is very little resistance in the valve and fluid flows freely to tank.

- In a pilot operated CBV application with **clamping** midstroke (pressure), the pressure on the blind side builds up (during clamping) forcing the CBV fully opened. All the system pressure can be used to clamp as opposed to clamping and supporting the weight.
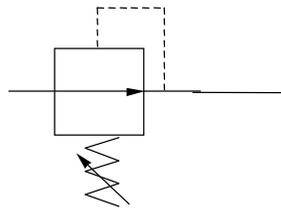
- CBV are designed to be slow in response. This provides a cushioning effect (deceleration)

- If a very large inertial load is present, then it may be very wise to use a RV between the load and CBV.
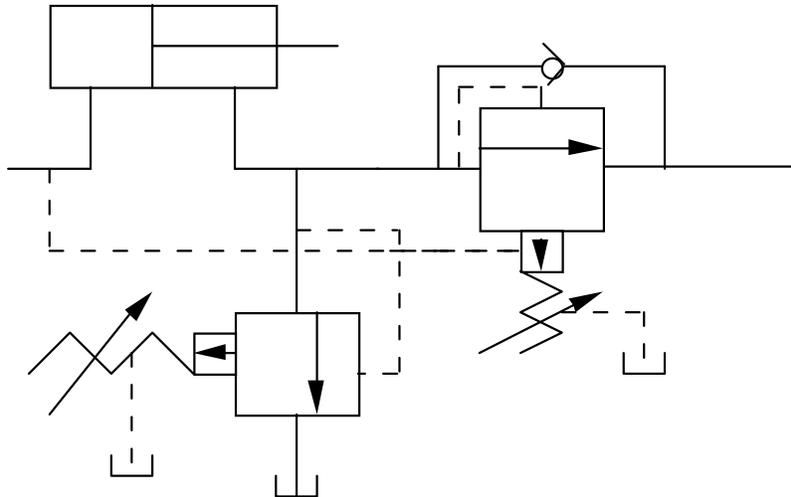

Figure 5.15 Preventing excessive pressure upstream to the CVB

5.1.2(f) Pressure Reducing Valves (Figure 5.16)

- Valves which maintain a reduced pressure at its outlet regardless of the higher inlet pressure
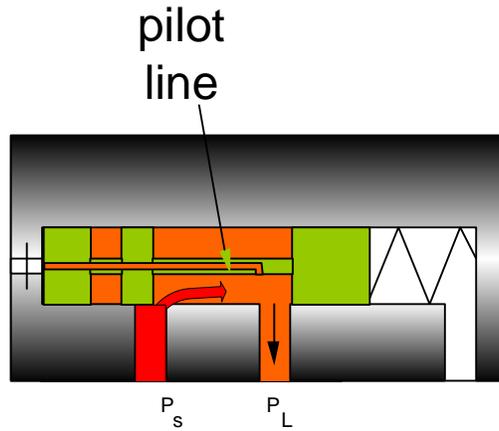- limits a system pressure to a circuit lower than the main circuit.

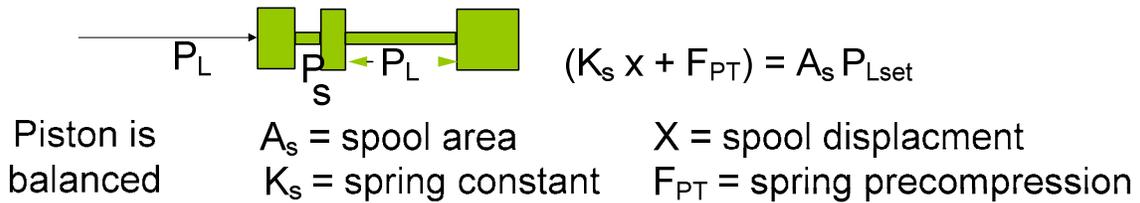Figure 5.17 illustrates an example of a direct operated piston type pressure reducing valve.

pilot
line

P_s P_L
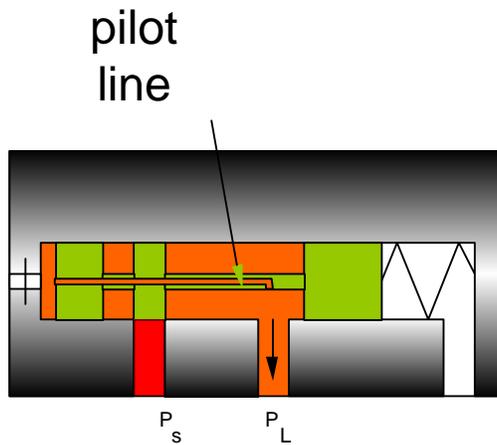
$$P_L > P_{Lset}$$

Spool closed

Figure 5.17 Direct operating pressure reducing valve(a)

$$P_L < P_{Lset}$$

Spool opened

Figure 5.17 Direct operating pressure reducing valve(b)

$$(K_s x + F_{PT}) = A_s P_{Lset}$$

Piston is balanced

A_s = spool area

K_s = spring constant

X = spool displacment

F_{PT} = spring precompression

Figure 5.17 Direct operating pressure reducing valve©

The down stream pressure (P_L) is ported to the left hand side via the pilot line. Since all other pressure forces are balanced, $P_L A_s$ must overcome the spring force which is in fact adjusted to be the desired pressure. When P_L is less than P_{Lset}, the spool is to the left allowing fluid to the downstream side. When the resistance in the circuit is such that the pressure rises to P_{Lset} the valve starts to close to maintain the set pressure.

Consider the two stage pilot operated spool pressure reducing valve shown in Figure 5.18. Its composite symbol is also shown in the figure.

Sensing orifce
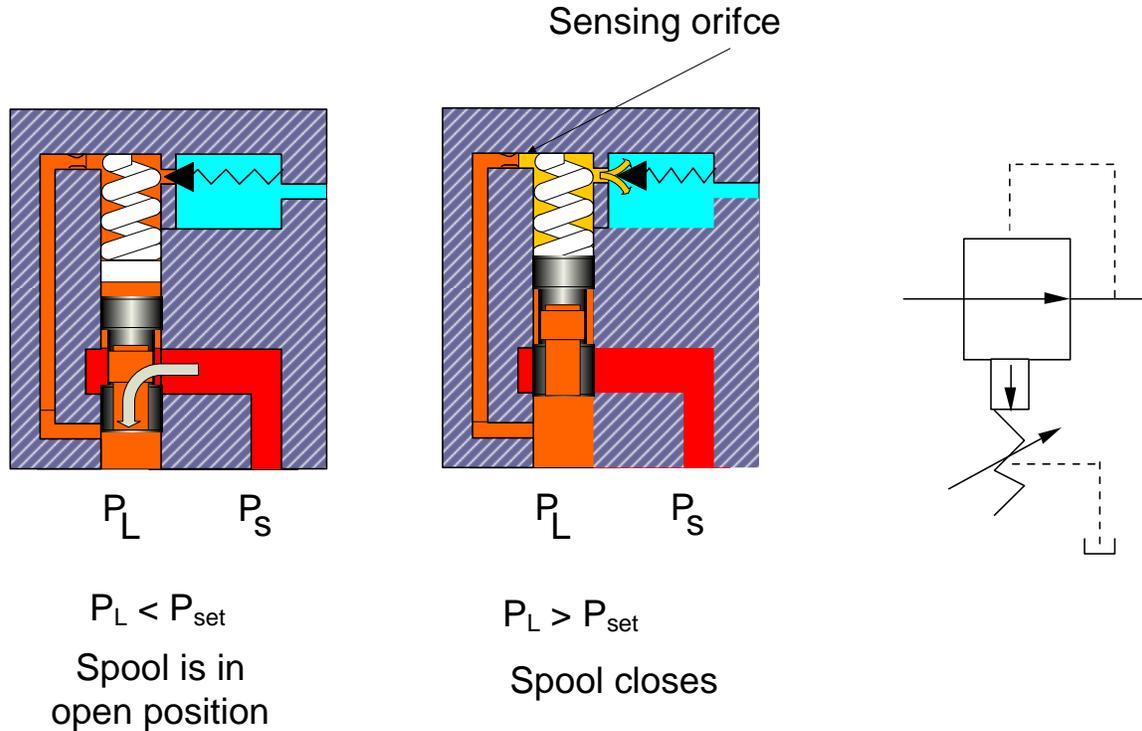
Figure 5.18 Pilot operated pressure reducing valve

P_L P_S P_L P_S

$P_L < P_{set}$ $P_L > P_{set}$

Spool is in   Spool closes
open position

The valve is a normally opened valve. When the downstream pressure becomes higher the preset value at the pilot, the pilot opens and ports fluid to tank. As the downstream pressure continues to rise, the pressure drop across the main spool increases (due to the sensing line orifice) and the main spool shifts up to its closed position.

It is important to realize that even though the valve is considered to be normally open, it is in fact only partially open if P_L is less than P_S. This is what happens if the pressure reducing valve is used as pressure regulator. A pressure regulator maintains the down stream pressures at a constant value which would be less than P_S

Figure 5.19 shows a very simple pressure reducing circuit. In this case, the upstream pressure could be 20 MPa (3000 psi) but the valve maintains the down stream pressure to 6.9 MPa (1000 psi).
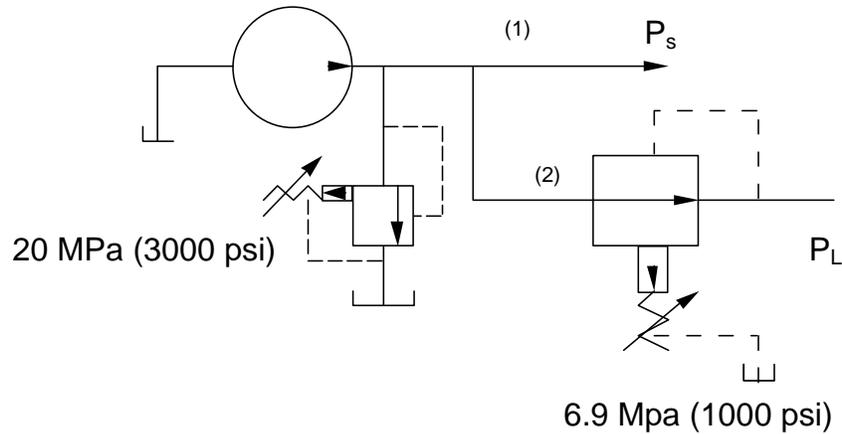
Figure 5.19 Simple pressure reducing circuit

5.1.2(g) <u>Unloading Relief Valve (Figure 5.20)</u>

-   This is a special application valve which is used in accumulator circuits to limit maximum pressure and unload the pump when the accumulator pressure is reached. This will be examined in greater detail later. However, when the load pressure reaches the unloading valve setting, the valve opens almost completely and stays open because the load pressure holds it there. But because the pump is now exposed to tank pressure (the valve is fully opened), there is little resistance to flow and hence the pressure drops to almost tank.

-   What keeps the relief valve opened?

-   In between the load and the pump/valve, is what is called a check valve which allows flow in one direction. So, no back flow from the load to the tank via the relief valve is permitted. Thus, the load pressure stays at a value dictated by the load.

-   So if the load pressure drops, what prevents the relief valve from opening again and hence possibility setting up an unstable situation due to repeated opening and closing of the relief valve?

-   The relief valve has built in damping in its design as well as a closing characteristic that is very similar to hysteresis. Thus, the valve does not close at the same value it opens but at some smaller value allowing the load pressure to drop somewhat before the valve closes again.

From
Pump

To the load
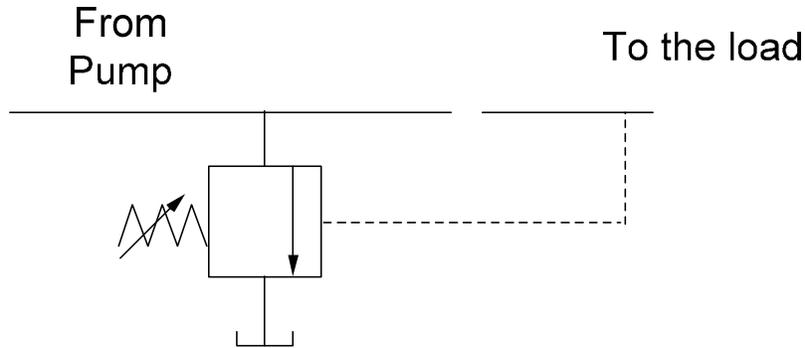
Figure 5.20 Unloading relief valve

5.1.2(h) Hydraulic Fuse

-        Device with a frangible disk which establishes max. P. in a circuit by rupturing at
a preset pressure.

5.2.7   Unloading Valve

Same as a pilot CBV except piloted upstream to the valve with a CV.
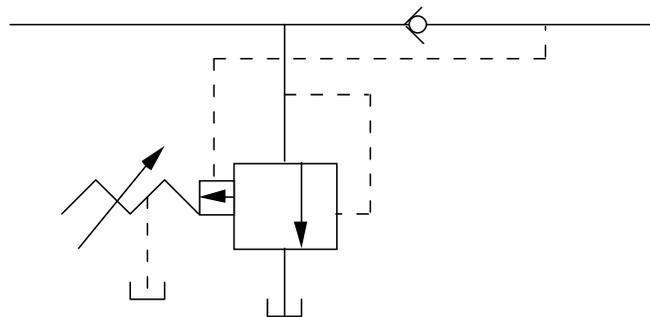
Figure 5.21

-Opening pressure and closing pressure are different (by design)

- This allows an accumulator to be charged and discharged to a desired lower
pressure, before having to be recharged again.

5.2.8 Cross-over relief valves

Consider the circuit shown in Figure 5.22.
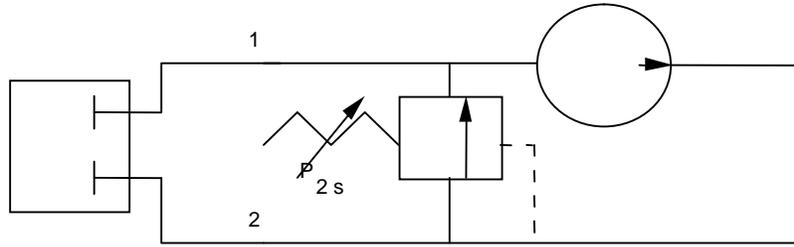
Figure 5.22 Crossover relief valves

When the directional control valve is closed, the inertia of the load would cause P_2 to increase and break the hose (possibly). Side 1 would cavitate. The large P_2 would rapidly decelerate the load.

The presence of a cross-over RV :

(a) would allow P_2 to increase to P_{2s} providing a back pressure on the motor (decelerate).

(b) would result in the fluid which is displaced by the motor to be recirculated back to the inlet of the motor. There is no cavitation.

In the reverse direction, the pressure must be less than P_{2s} or the cross-over RV would interfere with reverse motion.

RULE: P_{2s} should be approximately 150-200 psi > than $P_{reverse\ max}$ or any other pressure limiting device in the downstream line.

Consider the following scenario.
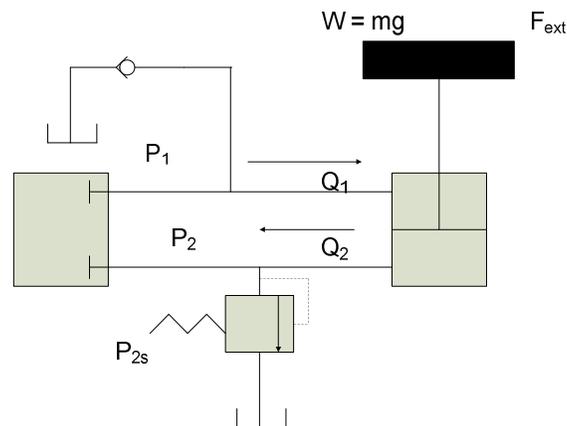
Figure 5.23 Example

As in the previous case, when the Directional control valve is closed, P_2 increases, P_1 decreases and cavitates. We cannot use a cross-over RV because when P_{2s} is reached, Q_2 from actuator is $> Q_1$ displaced by the actuator. Therefore P_1 actually increases forcing the system all the way down.

With the above configuration, a make up valve prevents cavitation.

5.3   Piston vs. cartridge

You will find that the way in which pressure reduction is accomplish will vary significantly with various manufacturers. In addition, the type of insert will change. Below is a comparison between piston type and cartridge type valves

Piston type   versus   Cartridge

- sensitive to contaminants   - small mass
- bad overshoot   - accommodates
- poor response (dead zone)   large flow vs small
 - 110-150 ms   stroke
                                                 - 50 - 60 ms

5.4 Hydraulic Symbols
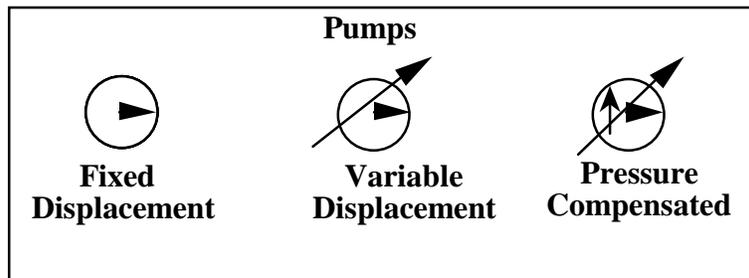
**Composite Drawing of a Pressure
Compensated Pump**

Motors

Fixed
Displacement

Variable
Displacement

Accumulators

Spring
Loaded

Gas
Charged

Reservoirs

**Resevoir
vented below
the fluid level**

**Reservoir
vented above
the fluid level**

Actuators

**Double Acting
Single Rod
(with cushion)**

**Double Acting
Double Rod**

**Limited Rotational
motor**
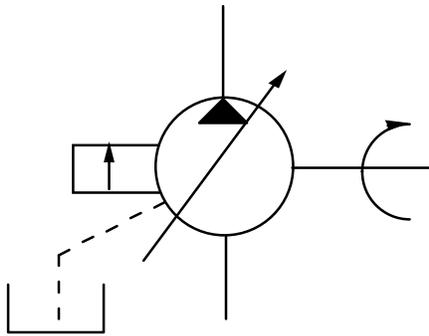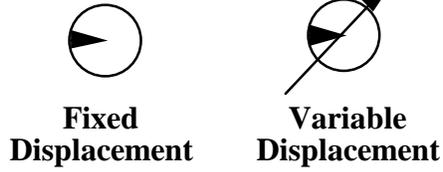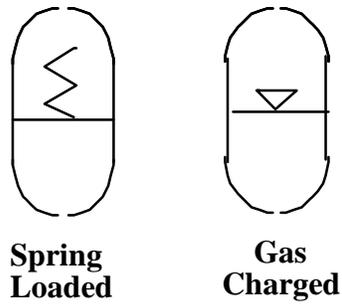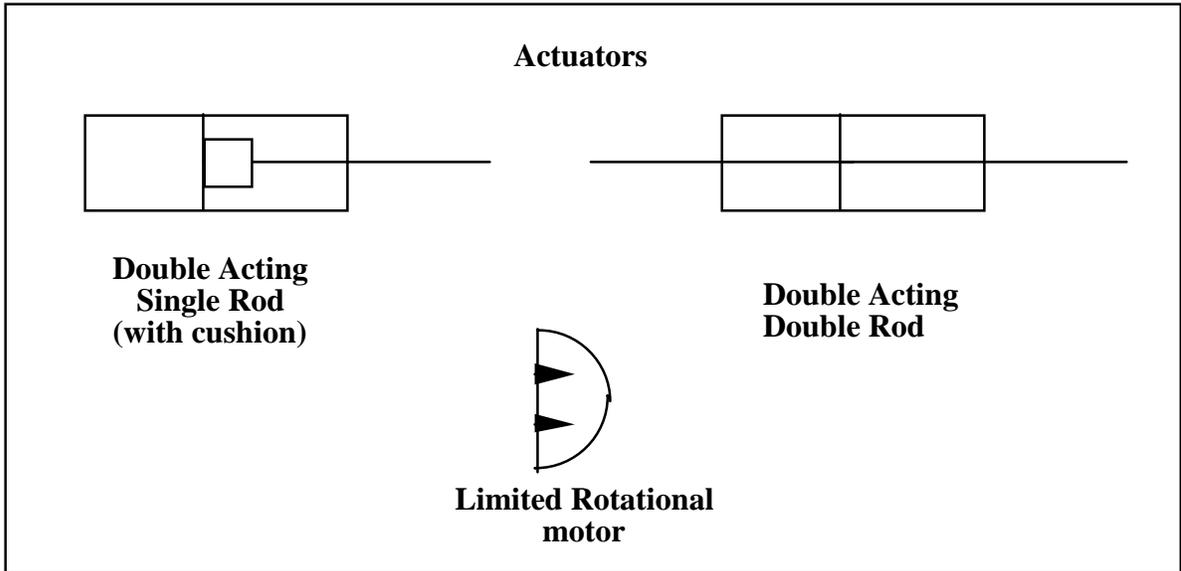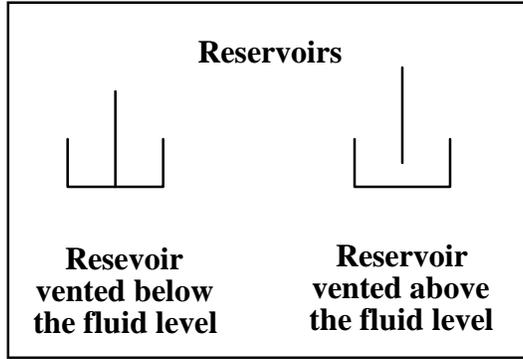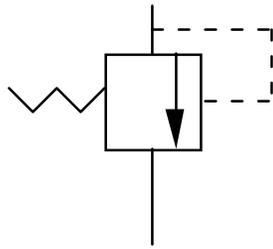
Pressure Valves

**Counterbalance
or
Sequence Valve**
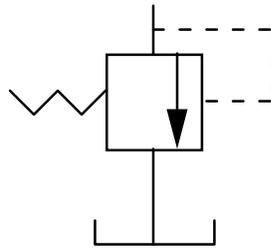
Relief Valve
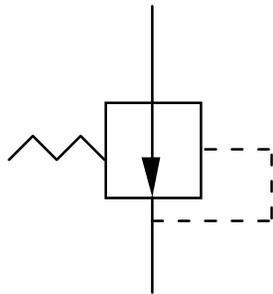
**Pressure Reducing
Valve**
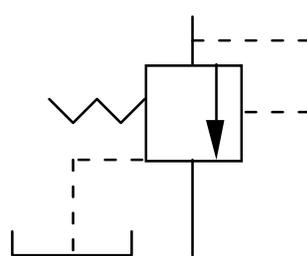
**Pressure Valve
with internal
venting**

Composite Symbol

Hydraulic

Pneumatic

Pilot line   **Hydraulic Line**

Flow Modulation Valves

Fixed Area

Variable Area

**Pressure Compensated
Variable Area**

**Proportional
Fourway
Valve**

Pressure Intensifier

Filter

Heat Exchanger

Normally Open

Normally Closed

Check Valve

Pilot Check Valve

**Two Position
Two Way
Normally Opened
Descrete Positions**

**Two Position
Two Way
Normally Closed
Descrete Positions**

**Two Position
Two Way
Normally Opened
Infinite Positions**

**Two Position
Two Way
Normally Closed
Infinite Positions**

Four Way Valves

Four Way
Three Position
Infinite Position
Closed Center
Spring Centered
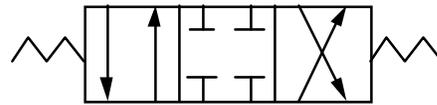
Four Way
Three Position
Descrete Position
Closed Center
Spring Centered
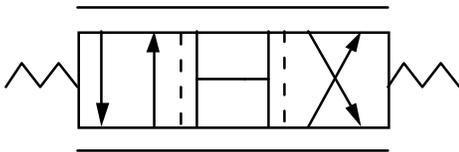
Four Way
Three Position
Infinite Position
Open Center
Spring Centered

Four Way
Three Position
Decrete Position
Open Center
Spring Centered

Three Way Valves
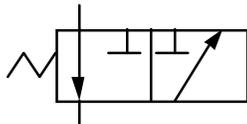
Two Position
Three Way
Normally Open
Directional Control
Valve
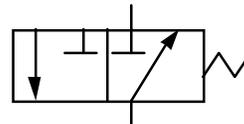
Two Position
Three Way
Normally Closed
Directional Control
Valve

Center Positions

Closed Center

Open Center

Reverse Tandem Center

Tandem Center
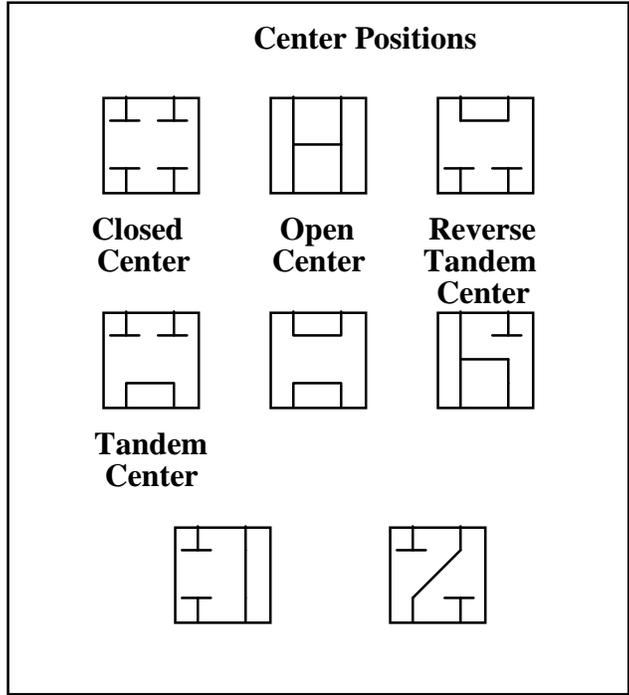
Valve Actuators
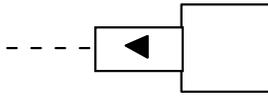
**Pilot Operated
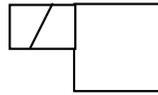Released Pressure
remote exhaust**
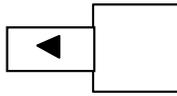
**Pilot Operated
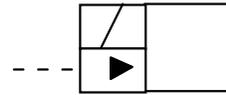Released Pressure
internal return**
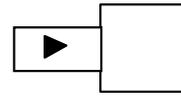
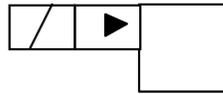**Pilot Operated
Pilot Pressure
directly acting on spool**
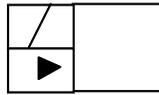
**Solenoid or
Internal Pilot
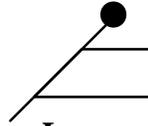Operated**

**Solenoid
Operated**

**Solenoid or
External Pilot
Operated**
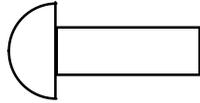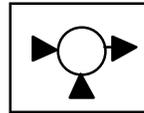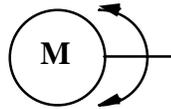
**Solenoid
and Internal
Pilot**

Other Actuators

Detent

Lever

Push Button

Servo Controlled

M

Electric Motor