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Pneumatic and Hydraulic Systems

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Adapted from the work of Dr Hengan Ou, and Dr Simon Lawes

Outlines

- Hydraulic and pneumatic actuation systems
- Cylinders
- Directional, pressure, process control valves
- Design of pneumatic systems

Learning Objectives

- Understand types and working principles of pneumatic and hydraulic actuators.
- Understand types and working principles of various control valves.
- To discuss common design features and considerations of pneumatic actuators

Hydraulic and pneumatic actuation

Pressurised fluids (liquid or gas) operating in piped circuits can actuate mechanical systems

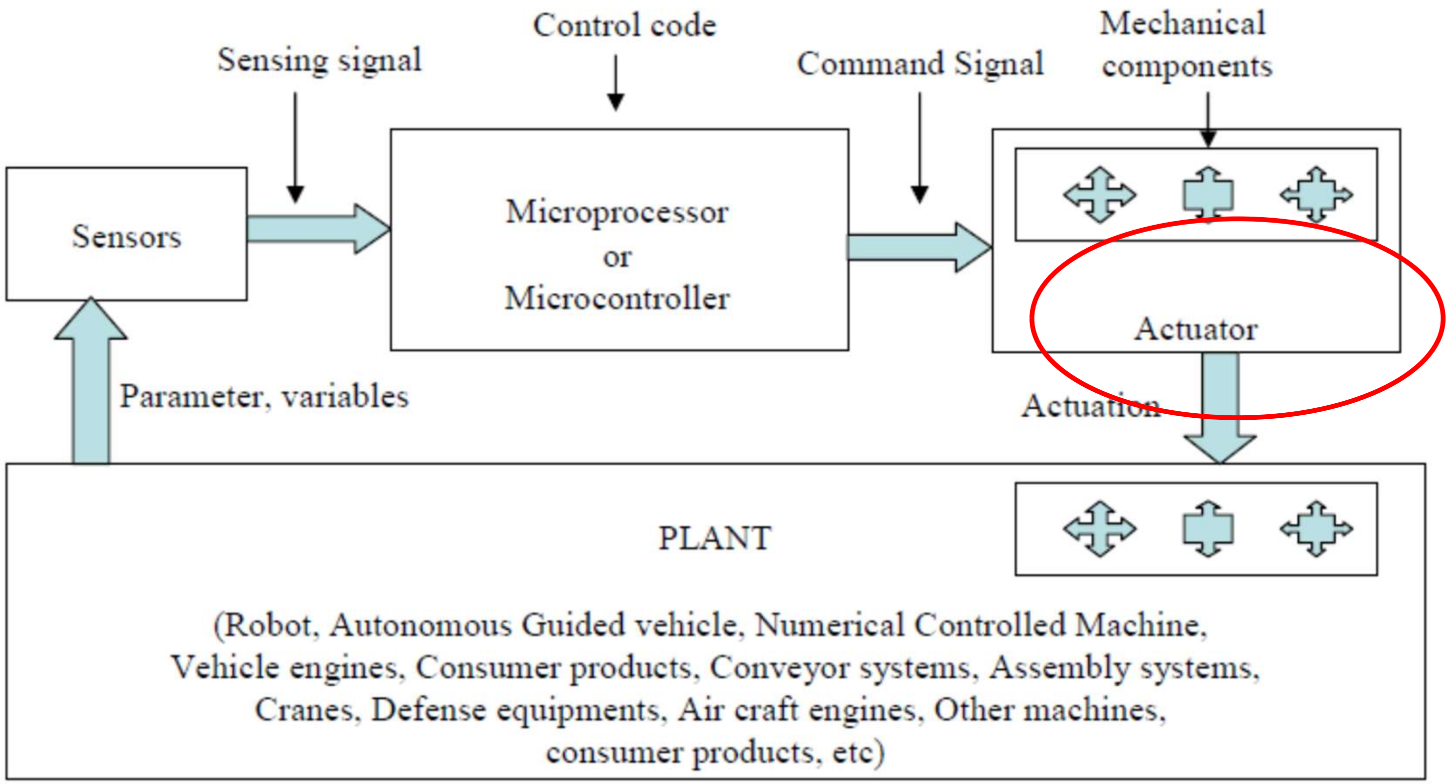
Pressurised liquid = Hydraulics

Pressurised gas (air) = Pneumatics

https://www.youtube.com/watch?v=Ea8X8ctgfQk

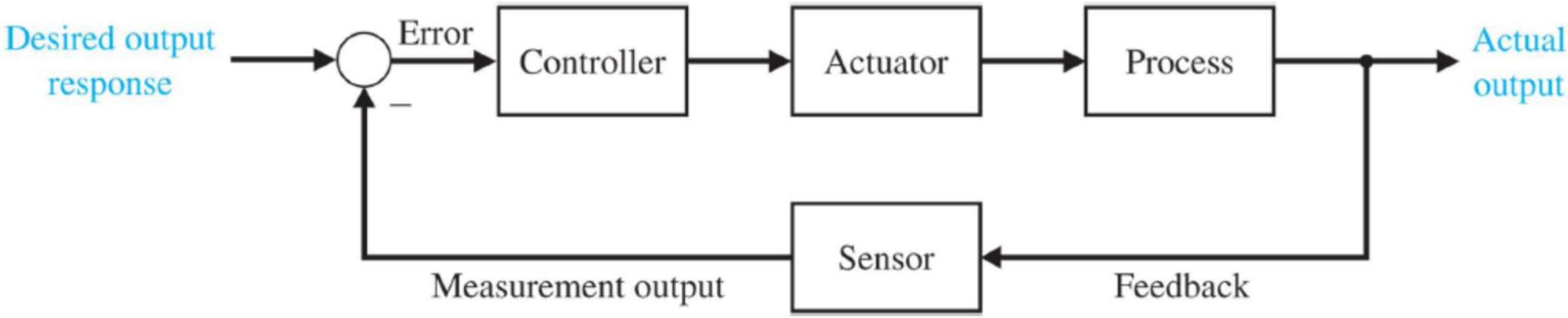
Actuation Systems

Actuation systems are the elements of control systems which are responsible for transforming the output of a microcontrollers or microprocessor or control system into a controlling action on machine or device.



Pneumatic & Hydraulic Actuation Systems

- Pneumatic deals with air pressure
- Hydraulic deals with fluid motion and pressure



Part 1

Hydraulic Actuation Systems

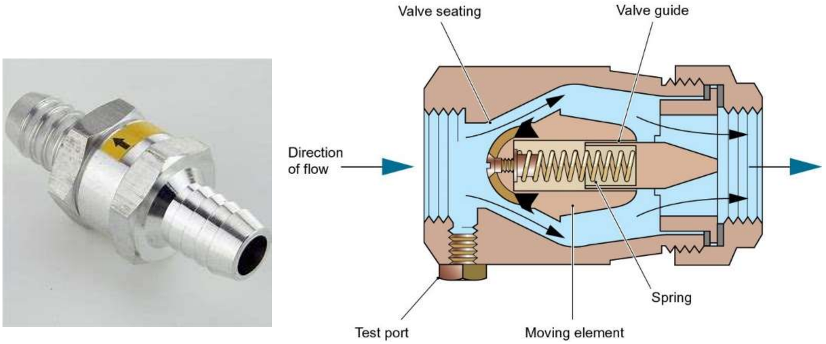
Typical Hydraulic Power System

- With a hydraulic system, pressurized oil (fluid) is provided by a pump driven by an electrical motor.

Typical Hydraulic Power System: Components

Hydraulic Pump

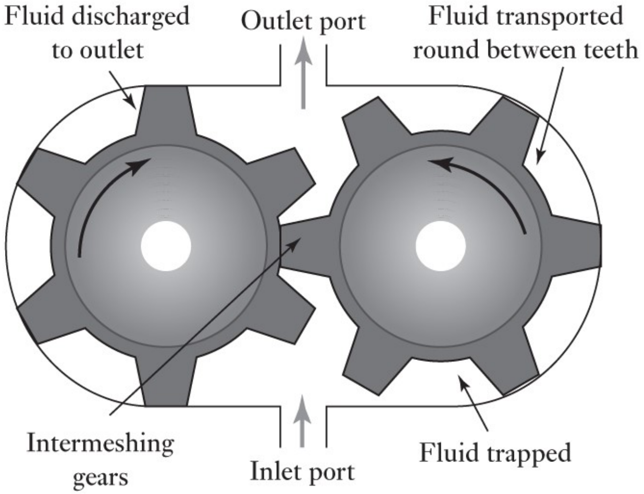
Pressure relief valve



Non return valve

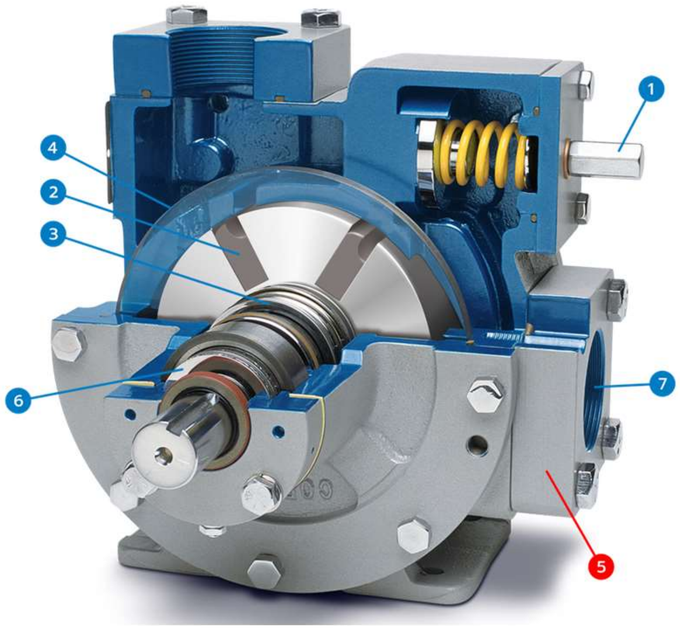
Accumulator

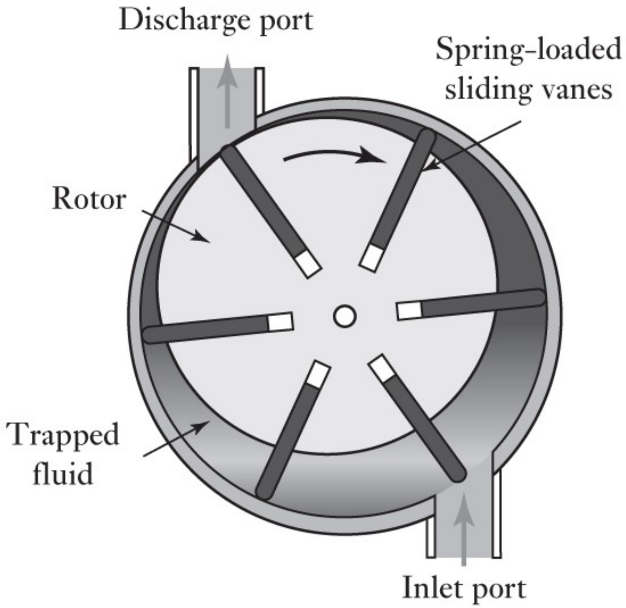
Gear Pump



- A gear pump uses the meshing of gears to pump fluid by displacement.
- They are one of the most common types of pumps for hydraulic fluid power applications.
- Gear pumps are also widely used in chemical installations to pump high viscosity fluids.

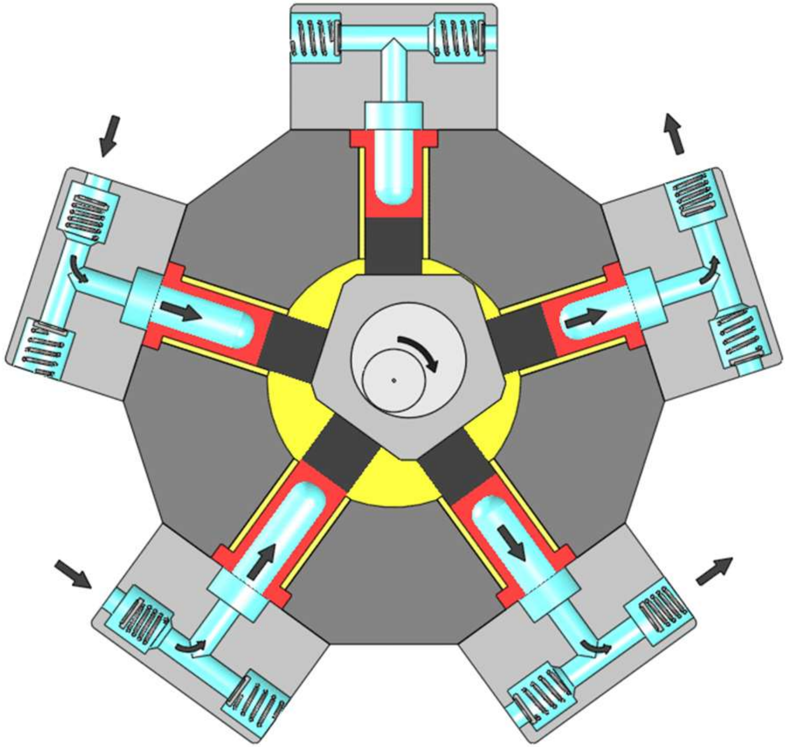
Van Pump

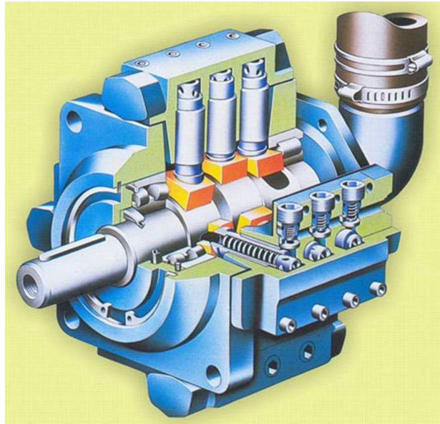


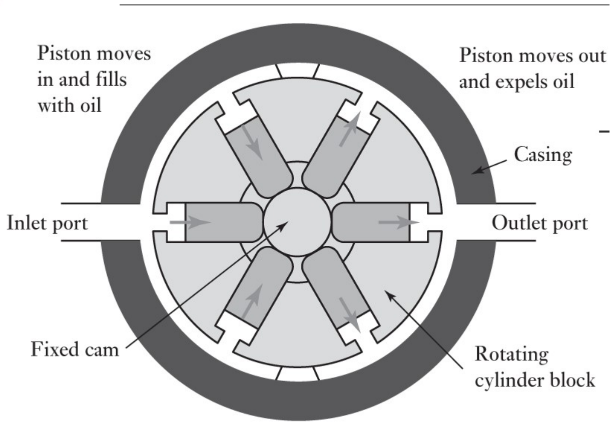


- A rotary vane pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside of a cavity.
- In some cases these vanes can have variable length and/or be tensioned to maintain contact with the walls as the pump rotates.

Radial Piston Pump

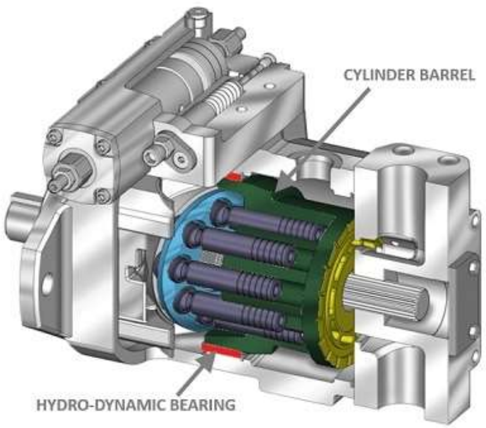


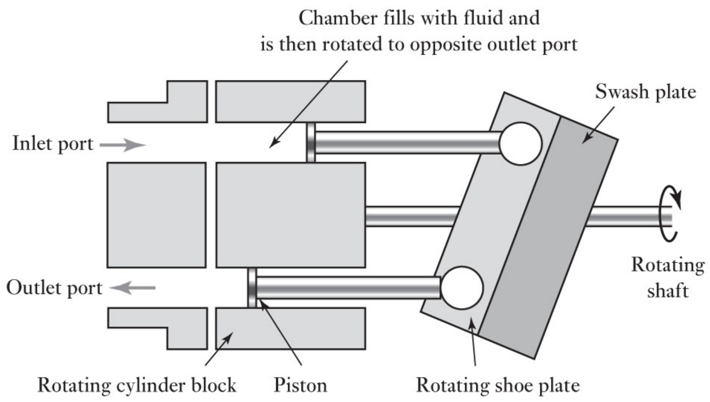


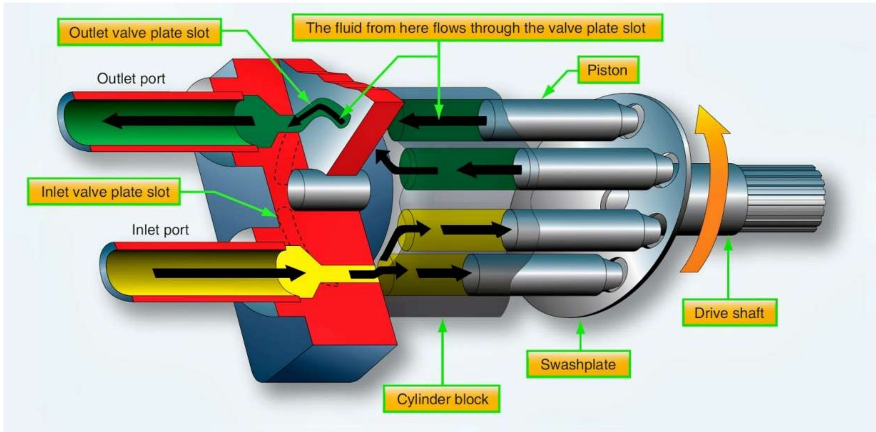


- A radial piston pump is a form of hydraulic pump. The working pistons extend in a radial direction symmetrically around the drive shaft, in contrast to the axial piston pump.

Axial Piston Pump with Wash Plate







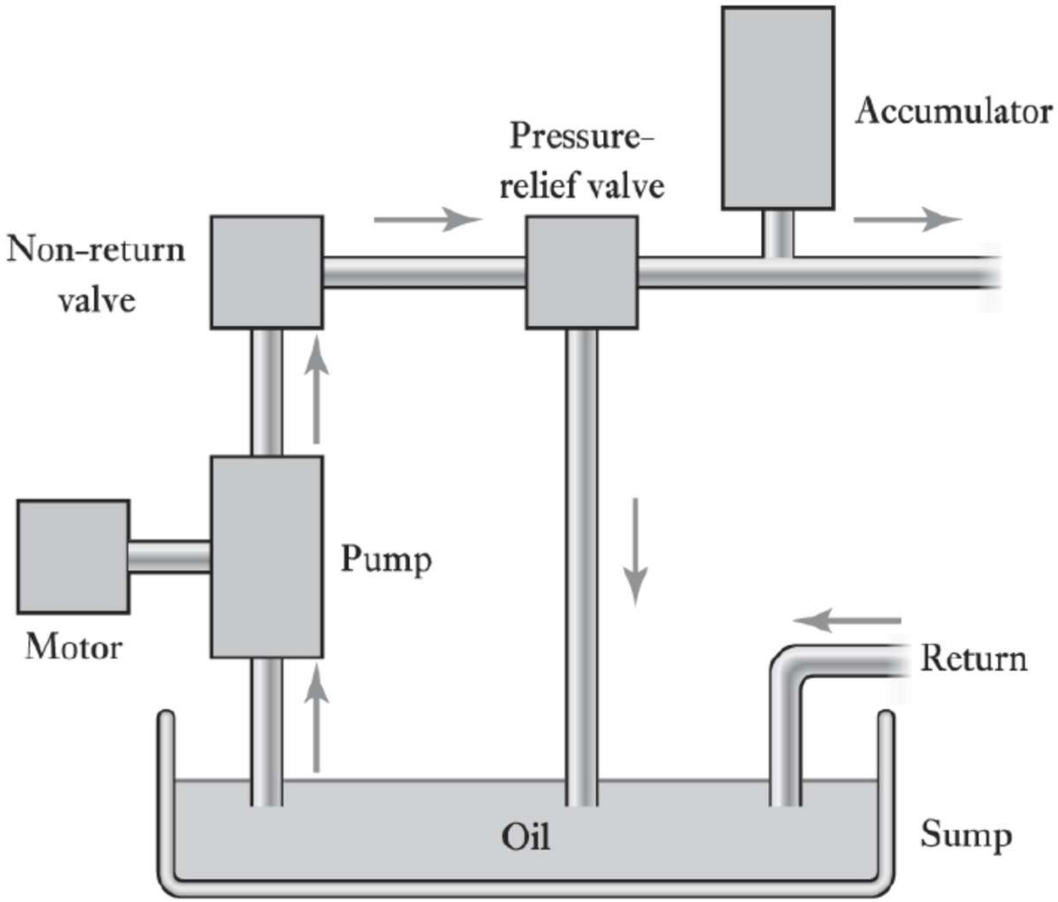
An axial piston pump is a positive displacement pump that has a number of pistons in a circular array within a cylinder block. It can be used as a stand-alone pump, a hydraulic motor or an automotive air conditioning compressor.

Typical Hydraulic Power System

- The pump pumps oil from a sump through a non return valve and an accumulator to the system, from which it return to the sump.

- The pressure relief valve is to release the pressure if it rises above a safe level,

- The accumulator is to smooth out any short term fluctuations in the output oil pressure

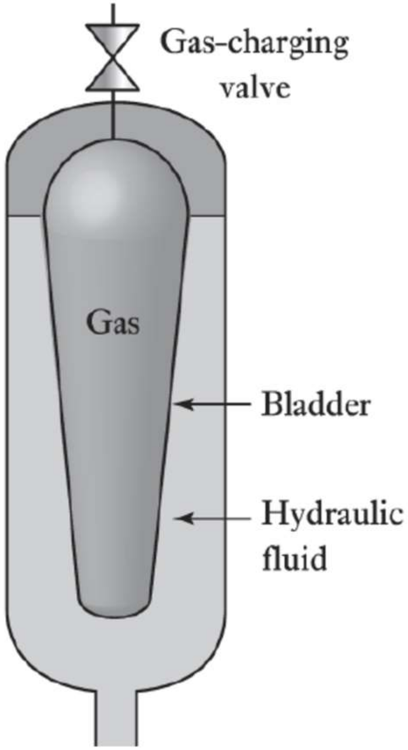


Accumulator

- Accumulator is a container in which the oil is held under pressure against an external force, which involves gas within a bladder in the chamber containing the hydraulic fluid.

- If the oil pressure rises then the bladder contracts increase the volume the oil can occupy and so reduces the pressure.

- If the oil pressure falls the bladder expands to reduce the volume occupied by the oil and so increases its pressure.



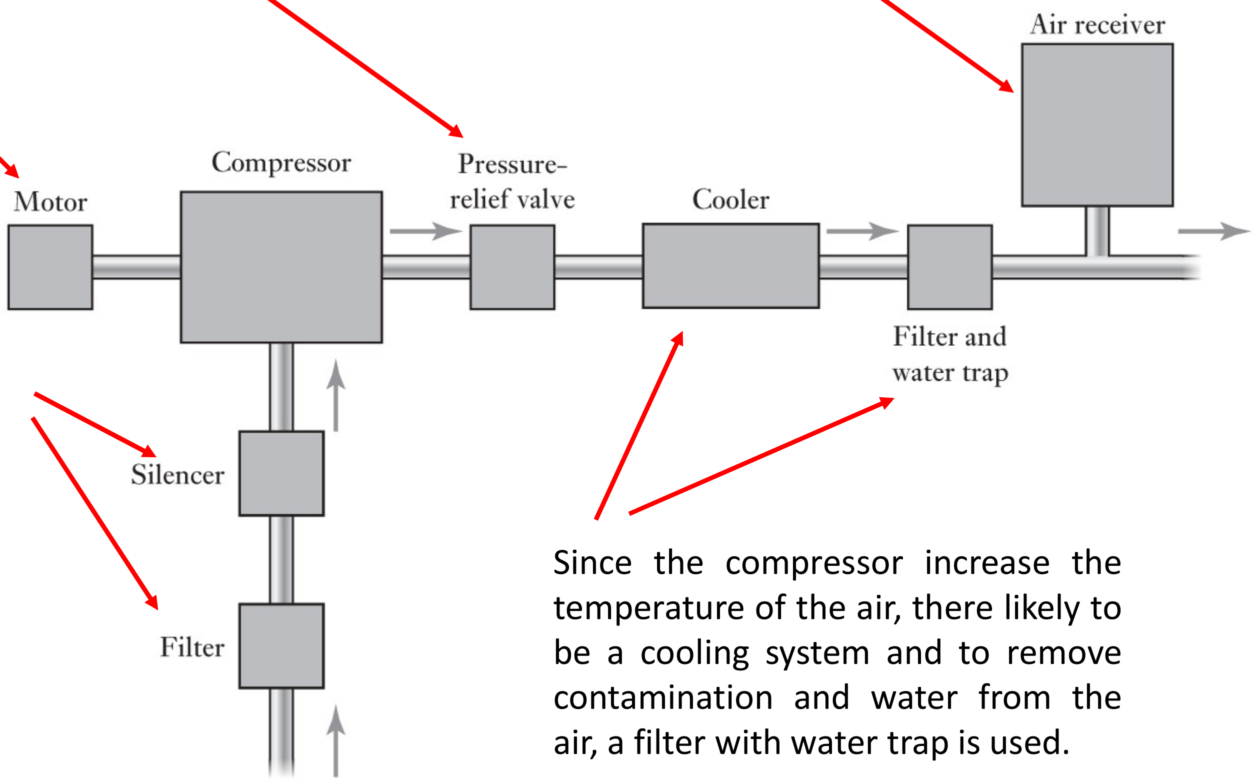
Typical Hydraulic Power System

A pressure relief valve provides protection against the pressure in the system rising above a safe level.

An air receiver increases the volume of air in the system and smoothes out any short-term pressure fluctuations.

In pneumatic power system, an electric motor drives an air compressor.

The air inlet to the compressor is likely to be filtered and via a silencer to reduce the noise level.



Since the compressor increase the temperature of the air, there likely to be a cooling system and to remove contamination and water from the air, a filter with water trap is used.

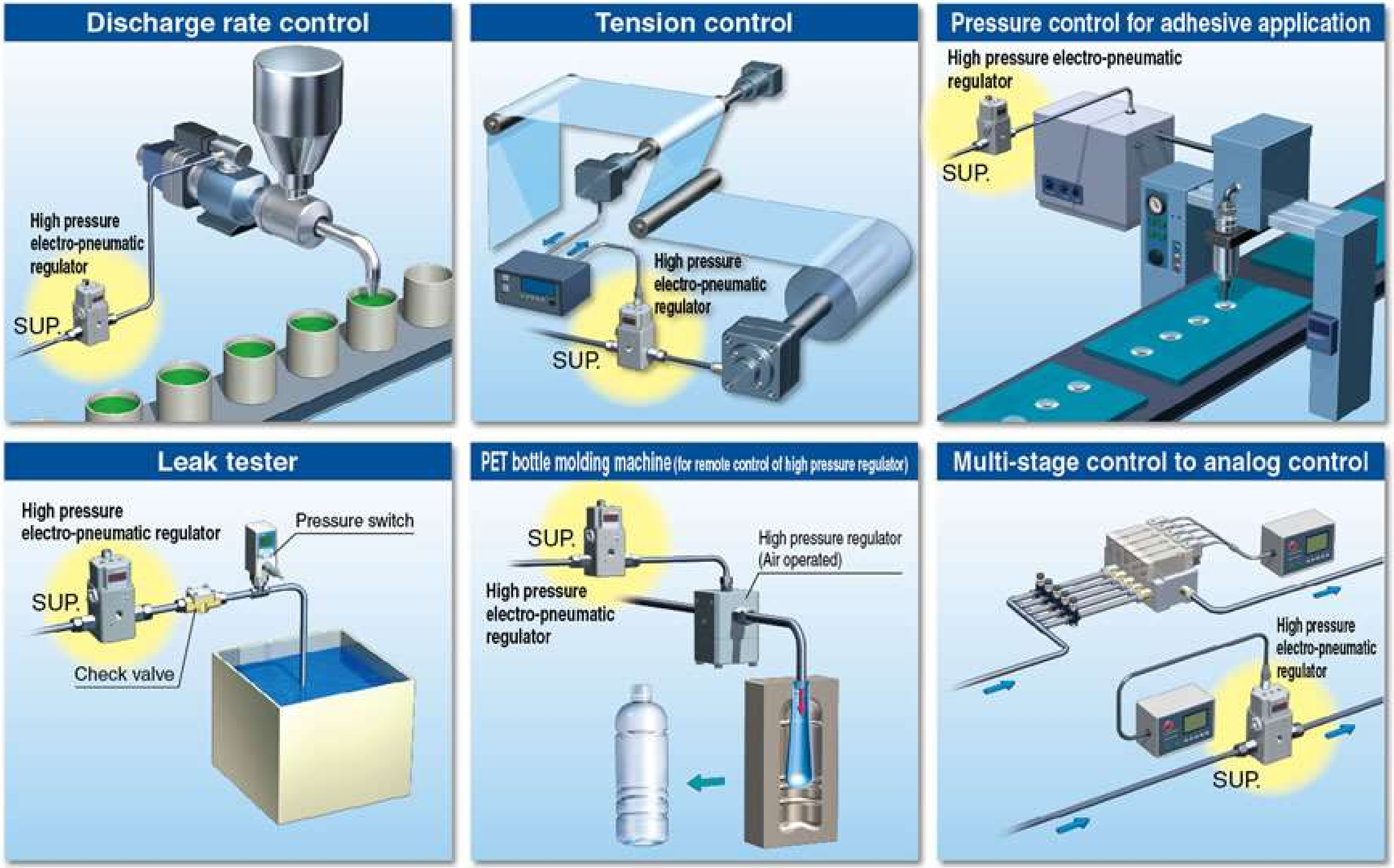
Advantages/Disadvantages of Hydraulic Power Systems

- Advantage:
  - Able to generate extremely large forces from compact actuators
  - Easy to control speed
  - Easy to implement linear motion
- Disadvantage:
  - Large infrastructure (high-pressure pump, tank, distribution lines)
  - Potential fluid leaks
  - Noisy operation
  - Vibration
  - Maintenance requirements, expensive
  - Characteristics of working fluids change with temperature and moisture

Part 2

Pneumatic Actuation Systems

Pneumatics: examples



Pneumatics

Advantages:

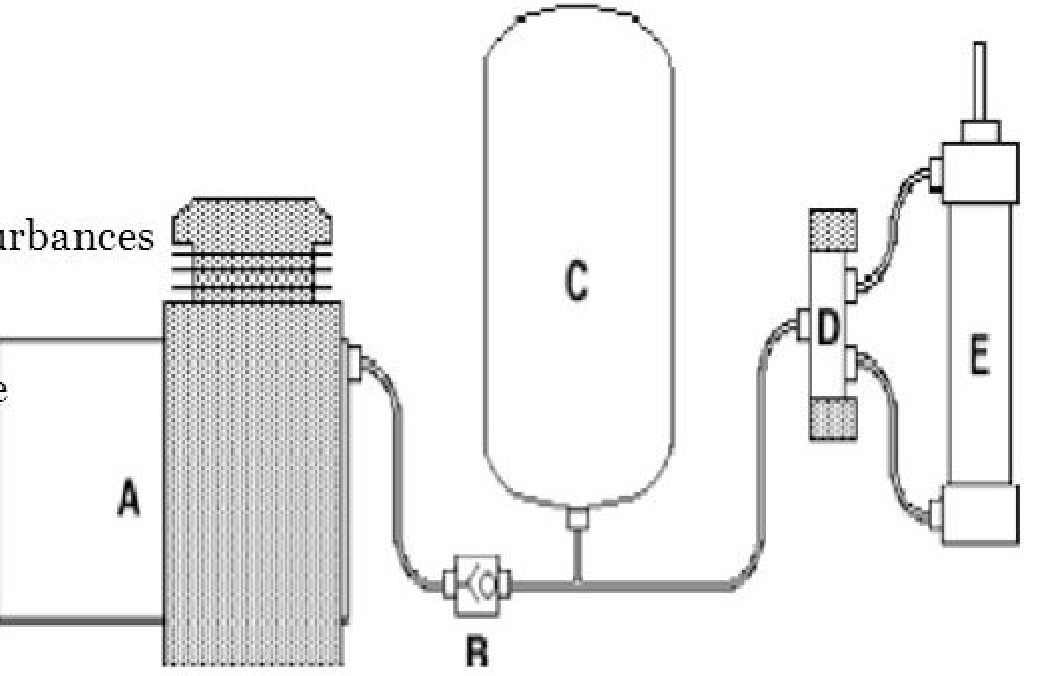
- Cheaper than electrical or hydraulic actuation
- Non-flammable so can use in harsh environments
- Simple to implement
- Controllable (pressure can be regulated)

Disadvantages:

- Does not produce a “stiff” system (air is compressible)
- Requires a compressor, air conditioning, and control valves
- Pressurised air can be dangerous

Pneumatic Components

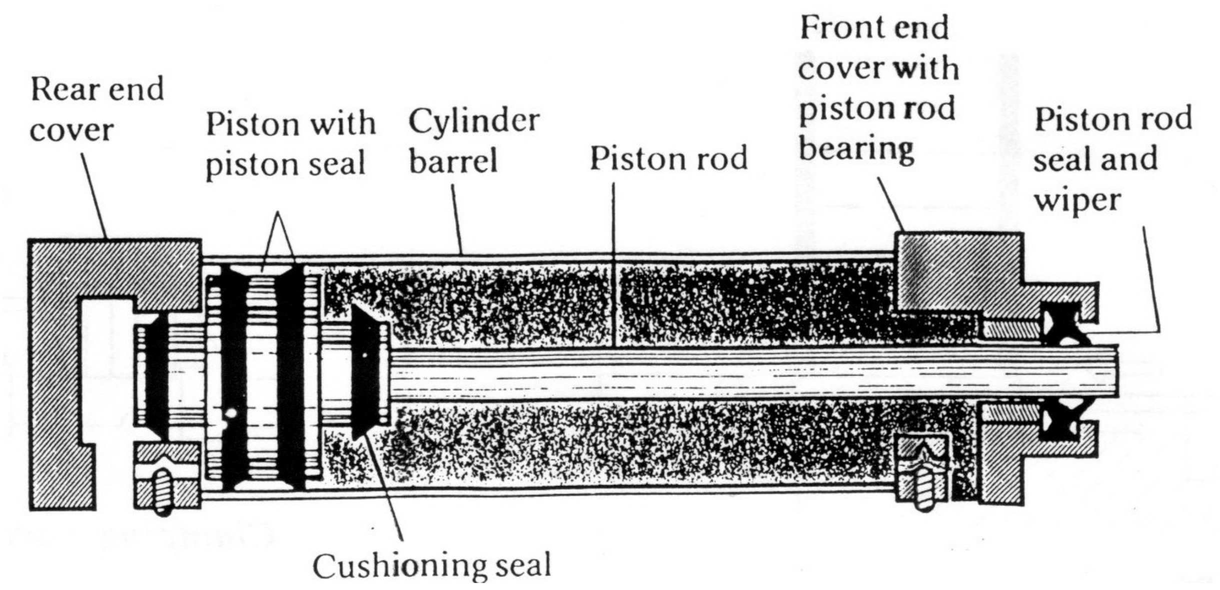
- **A) Compressor**
  - Pressurizes Air
  - Typically attached to tank for storage
  - Often is a centralized supply for multiple devices
- **B) Check Valve**
  - One way valve
  - Prevents backflow into compressor
  - Prevents compression loss when off
- **C) Accumulator**
  - Smooth air flow and unwanted disturbances
- **D) Directional Valve**
  - Direct Air flow
  - Stores energy and reduce turbulence
  - Electrical or manual operation
- **E) Actuator**
  - Transfers air energy into motion
  - Ex. Air Chisel



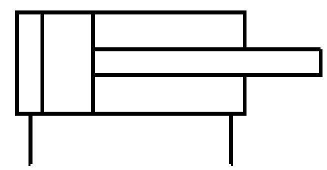
Pneumatic Actuators

Actuators generate a Force or Movement

Cylinders are the principal actuators for pneumatics:

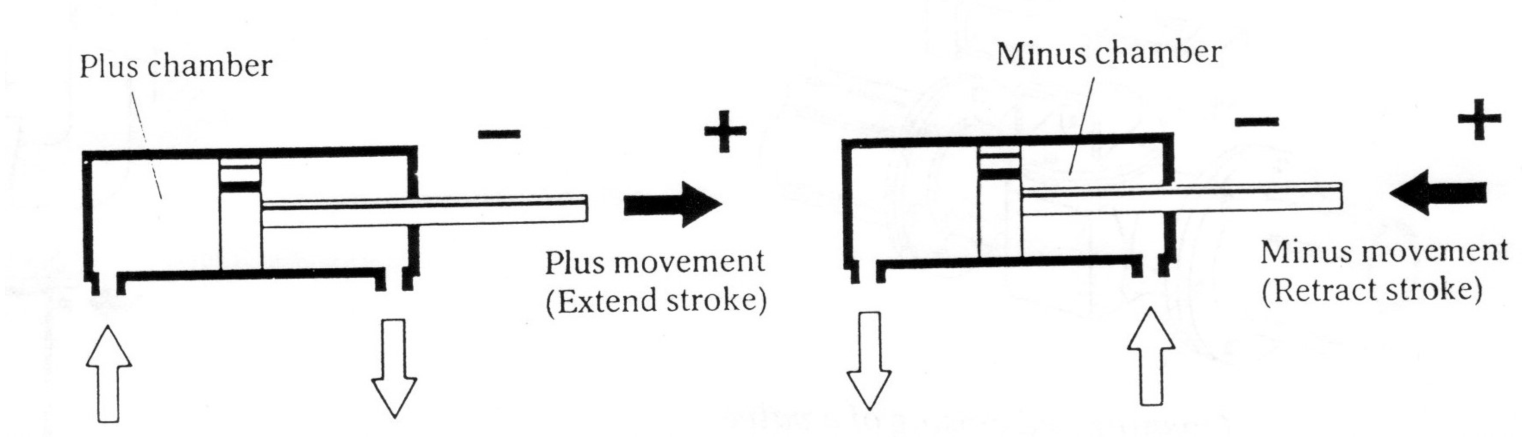


Double acting, single rod cylinder



BS ISO 1219 symbol of double acting, single rod cylinder

Terminology



Positive Stroke:

•Stroke extends

•Pushes to “Plus” position

Minus Stroke:

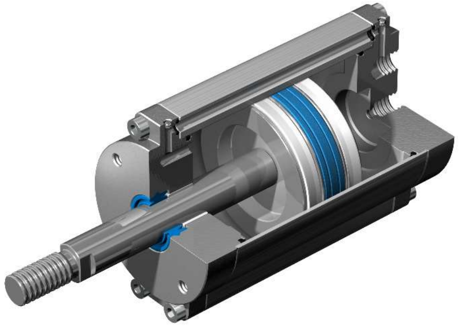
•Stroke retracts

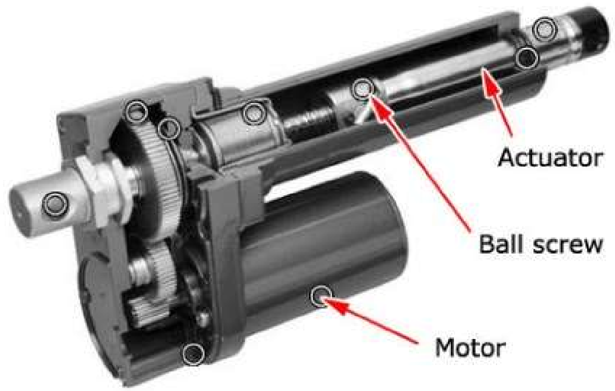
•Pushes to “Minus” position

Supply of compressed air to one chamber requires exhaust from the other chamber.

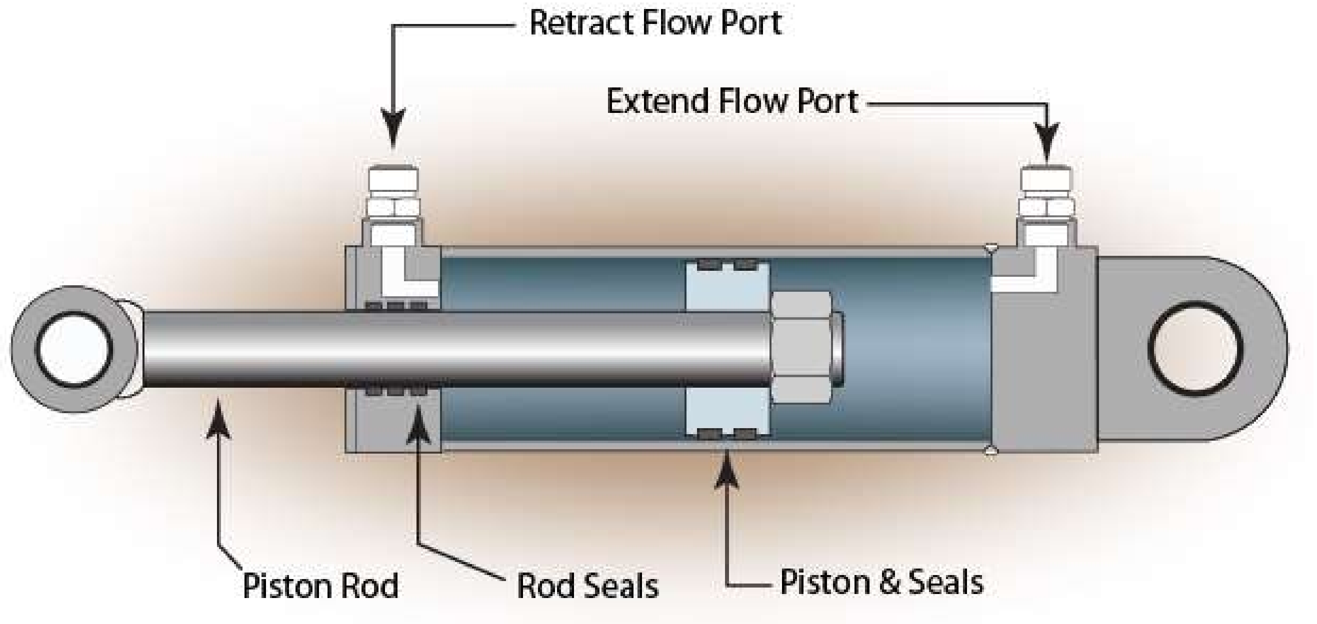
Hydraulic/Pneumatic Linear Actuators, (Cylinders)

- Both hydraulic and pneumatic actuators have the same principles differences being in size
- The cylinder consists of a cylindrical tube along which a piston/ram can slide





Hydraulic/Pneumatic Linear Actuators, (Cylinders)

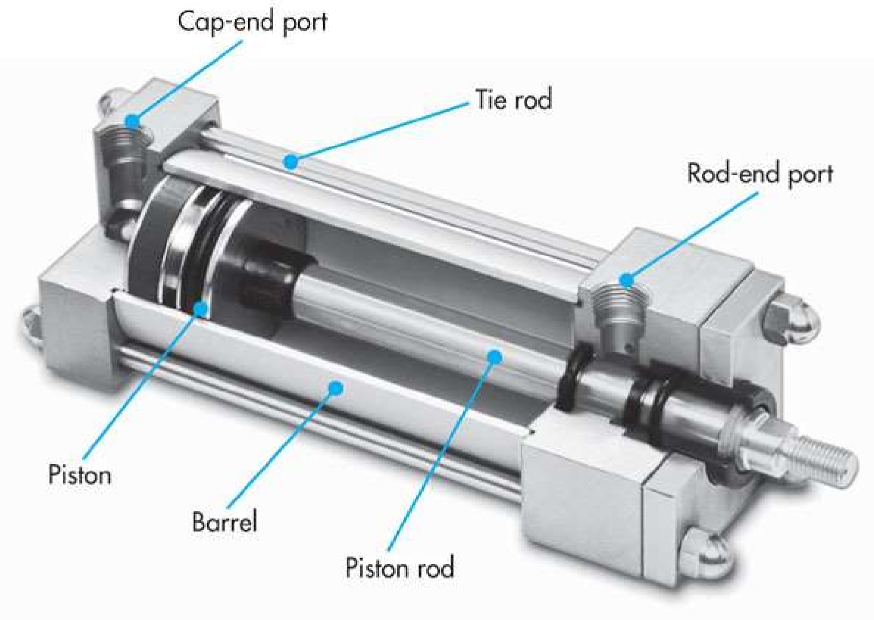


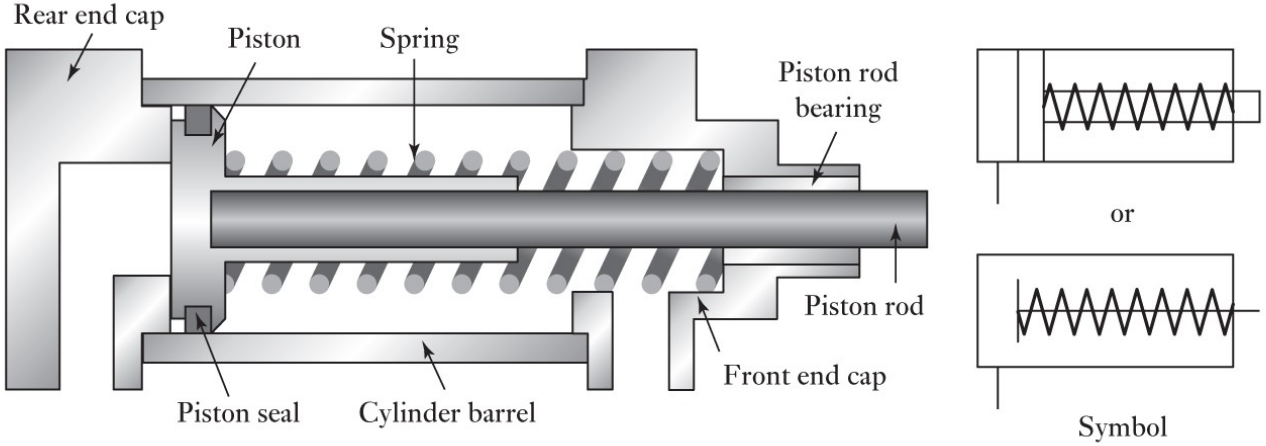
<u>They are of two types:</u>

- Single acting
- double acting

Single Acting Linear Actuator

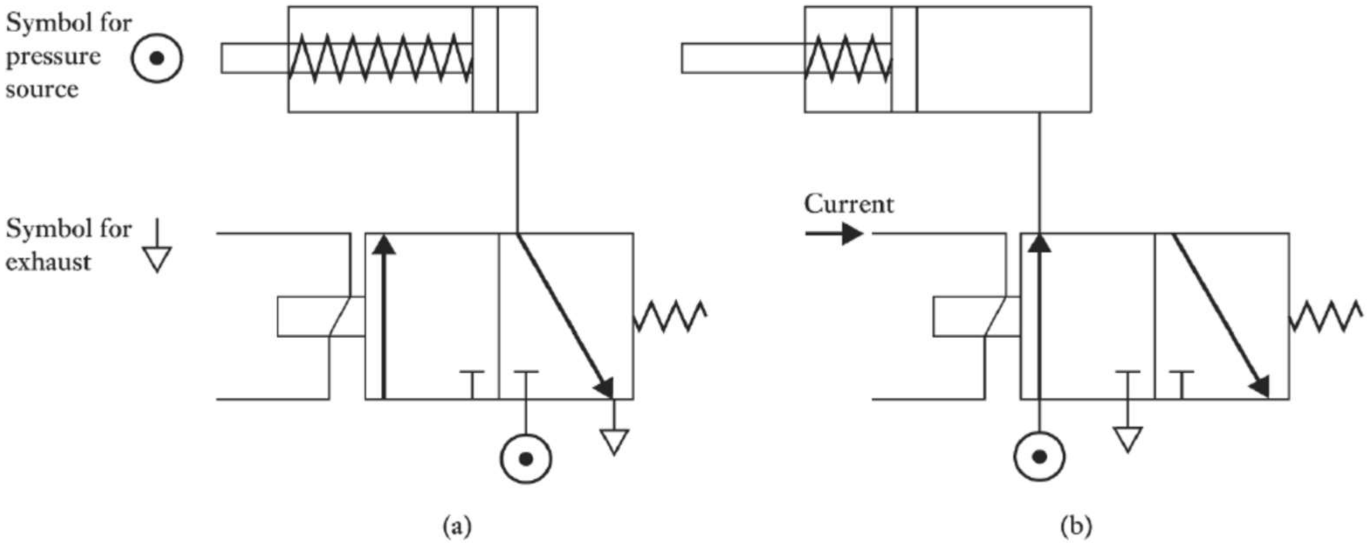
- The control pressure is applied to one side of the piston





Single Acting Linear Actuator

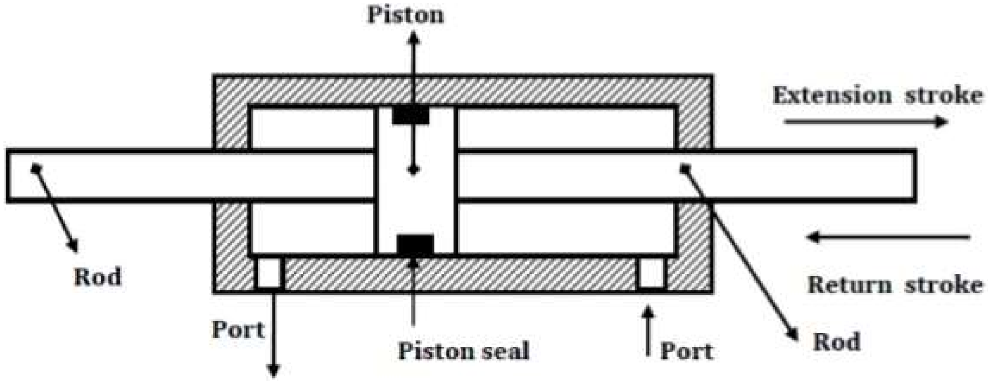
- When a current passes through the solenoid, the valve switches position and pressure is applied to move the piston along the cylinder. When current ceases, the valve reverts to it is initial position and the air is vent from the cylinder.

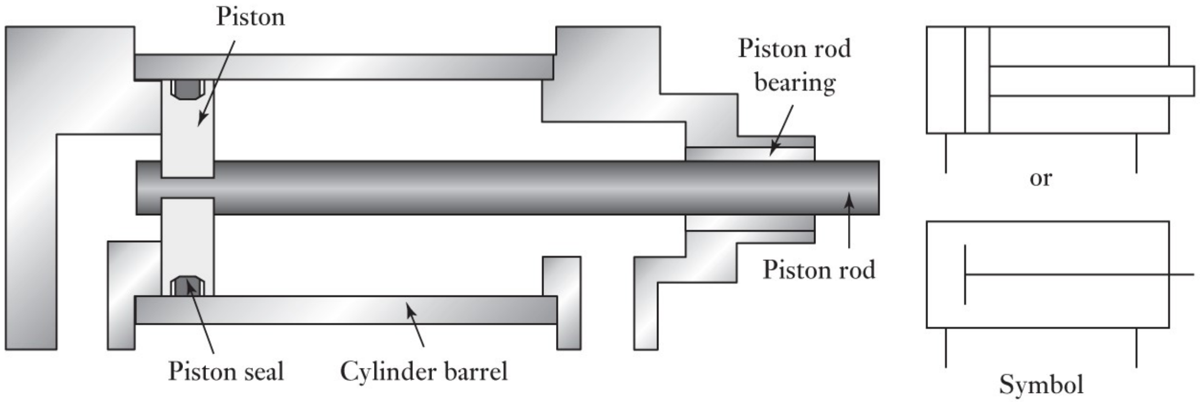


Control of a single-acting cylinder with
(a) no current through solenoid, (b) a current through the solenoid

Double Acting Linear Actuator

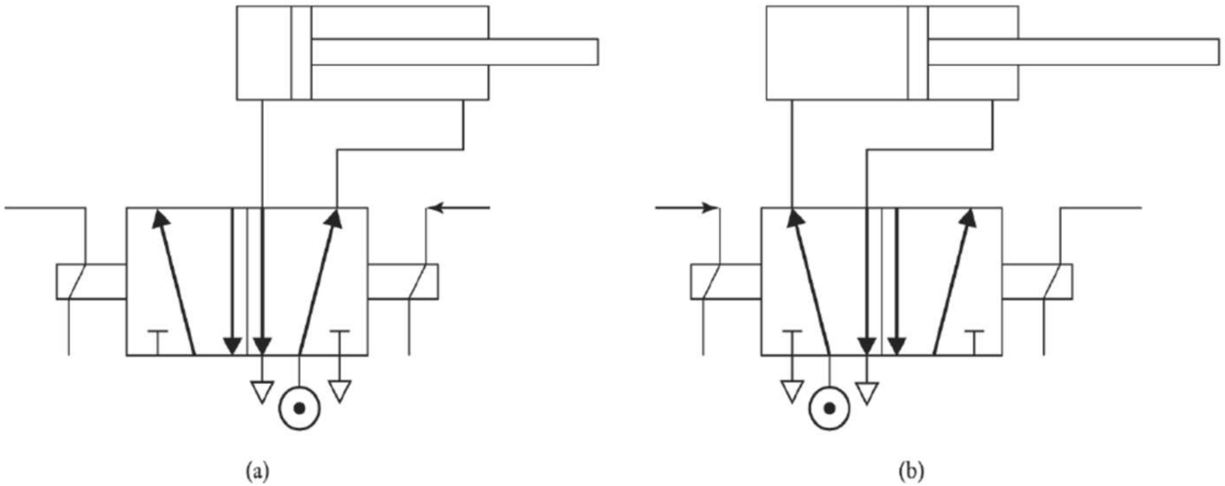
- Are used when control pressure are applied to both side of the piston. A difference in pressure between the two sides results in motion of the piston (No spring).





Double Acting Linear Actuator

- Current through one solenoid causes the piston to move in one direction.



Control of a double-acting cylinder with solenoid
(a) not activated, b) activated

Single Acting vs Double Acting Actuators

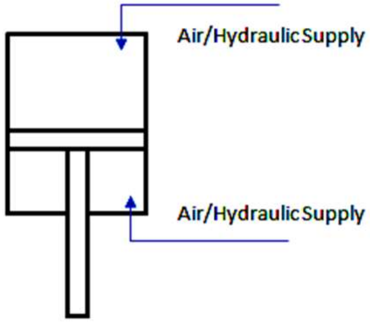


Illustration of Double Acting Actuator

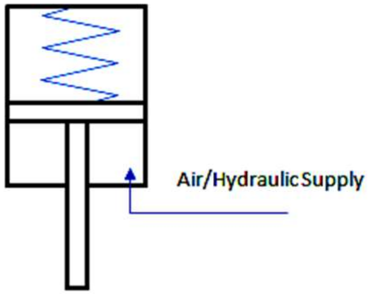
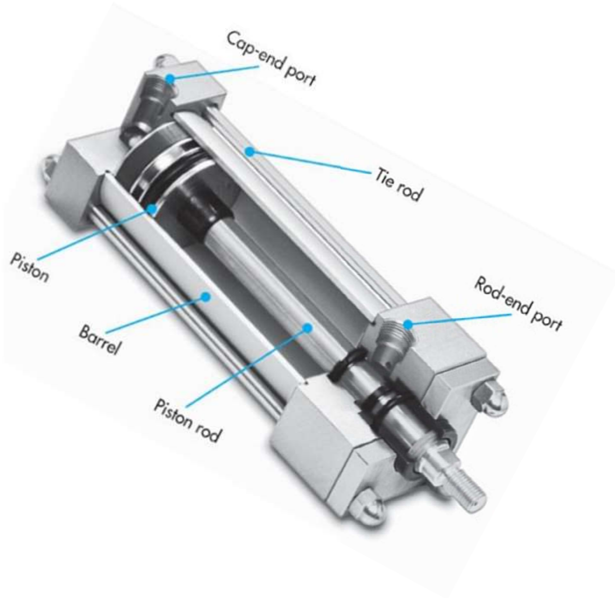


Illustration of Spring Return Actuator



Application	Spring Return	Double Acting
Torque or Thrust	Low to High	Low to Very High
Safety Integrated System(SDV, BDV)	Simple, Reliable, Best Choices	A little bit complex, Secondary Choices
Fail in Last Position(Choke Valve)	More expensive, secondary choices	Best choices
Control application(Control Valve, Choke Valve)	Best for 8 inch size and below	Best for 10 inch size and above, also for high pressure applications.

https://instrumentationtools.com/single-acting-vs-double-acting-actuators/

Cylinder: Example

A hydraulic cylinder to be used to move a work piece in a manufacturing operation through a distance of 250 mm in 15s. if a force of 50 KN is required to move the work piece, what is the required working pressure and hydraulic liquid flow rate if a cylinder with a piston diameter of 150 mm is available.

Solution:

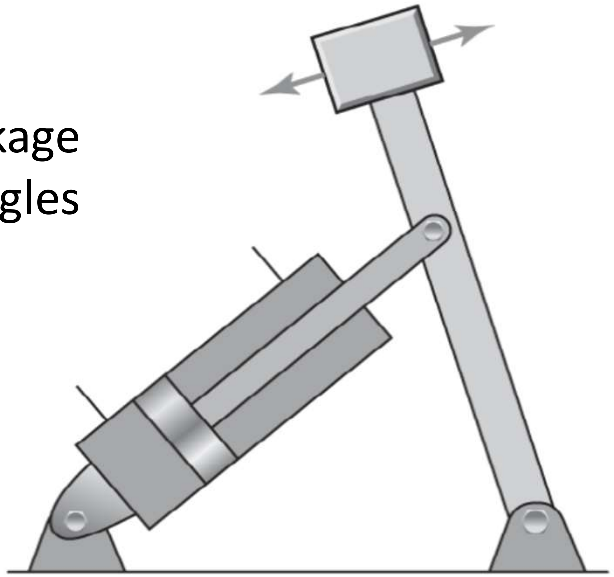
- $A = \pi r^2$ = π(0.15/2)2 = 0.0117 m2
- The working pressure = F/A = 50x103/0.017=2.8 Mpa
- The speed of a hydraulic cylinder = flow rate of the liquid through the cylinder v=Q/A
- Flow rate= Av=0.0117(0.250/15)=29.5x10-4 m3/s

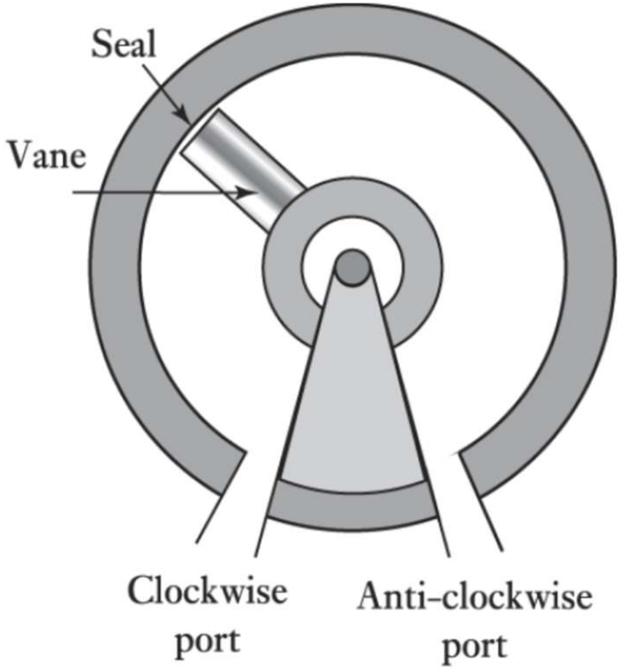
Rotary Actuators

- A rotary actuator can produce a rotary motion or torque. The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation.
- The most common actuators though are electrically powered.
- Other actuators may be powered by pneumatic or hydraulic power, or may use energy stored internally through springs.

Rotary Actuators

- A linear cylinder can, with suitable mechanical linkage be used to produce rotary movement through angles less than 360 degrees.





- Another alternative is vane type semi rotary. The pressure difference between the two parts causes the vane to rotate.

Part 3

Control Valves

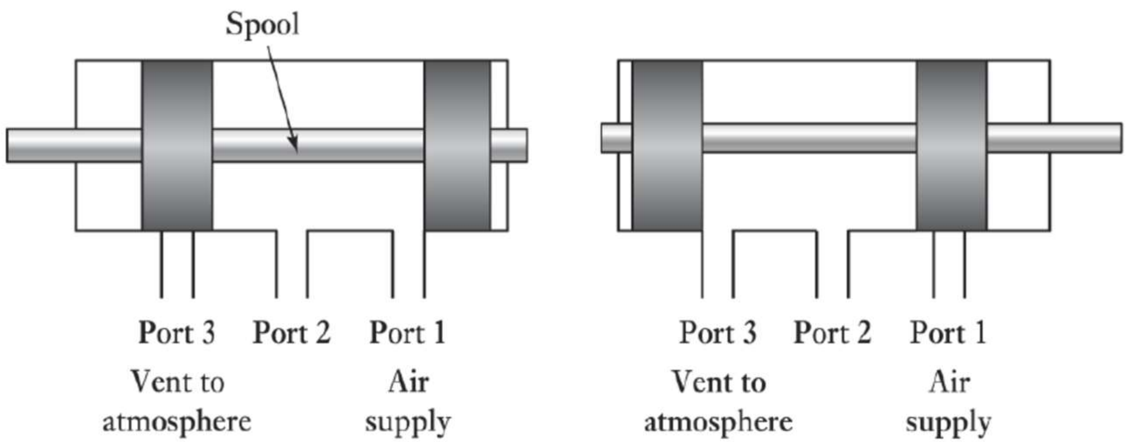
Directional Control Valves

- Pneumatic and hydraulic systems use directional control valves to direct the flow of fluid through a system; its ON/OFF devices either completely open or closed.

- They might be activated to switch the fluid flow direction by means of mechanical, electrical or fluid pressure signal.

Spool Directional Control Valves

- Move horizontally within the valve body to control flow. (Spool valves)



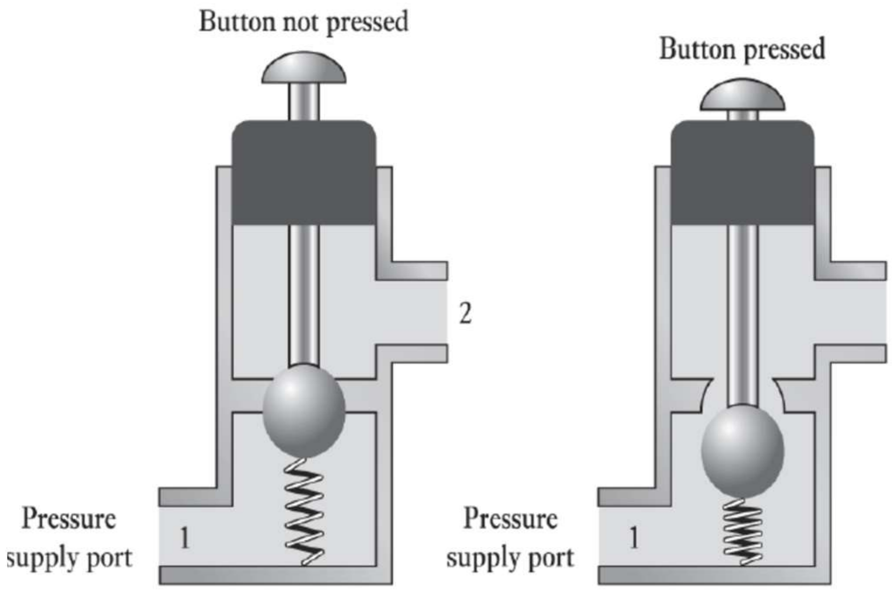
- Rotary spool valves (rotates to open and close ports)

2 Spool valve

3 Spool valve

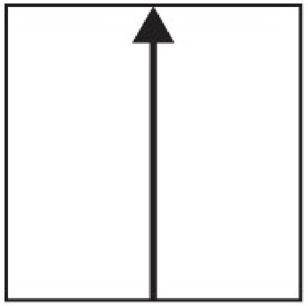
Poppet Valves

- This valve is normally in closed condition. In this valve, balls, discs or cones are used in conjunction with valve seats to control the flow.
- When the push button is depressed, the ball is pushed out of its seat and flow occurs as a result of port 1 being connected to port 2.
- When the button is released, the spring forces the ball back up against its seat and so closes off the flow.

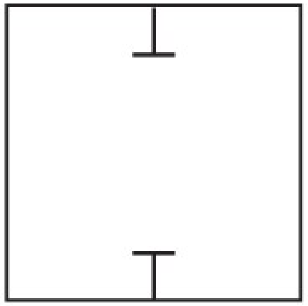


Valves Flow Symbols

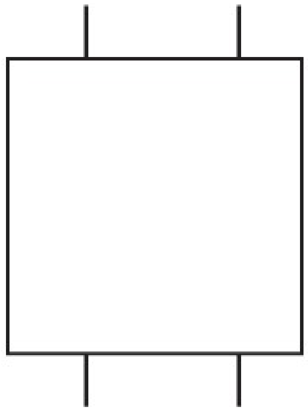
- The valve symbol consists of square for each of its switching positions. Thus for the shown poppet valve there are two positions, one with the button not pressed and one with it pressed. Thus two positions valve will have two squares, a three positions valve have three squares.



Flow path



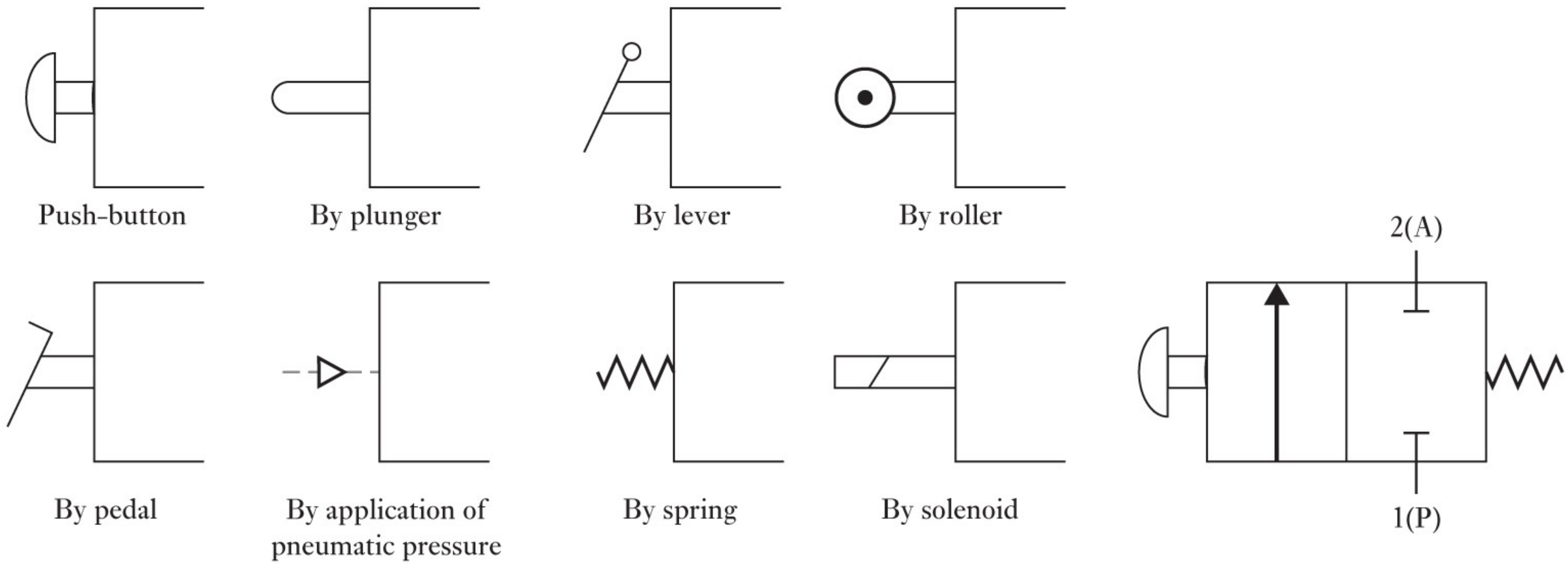
Flow shut-off



Initial connection

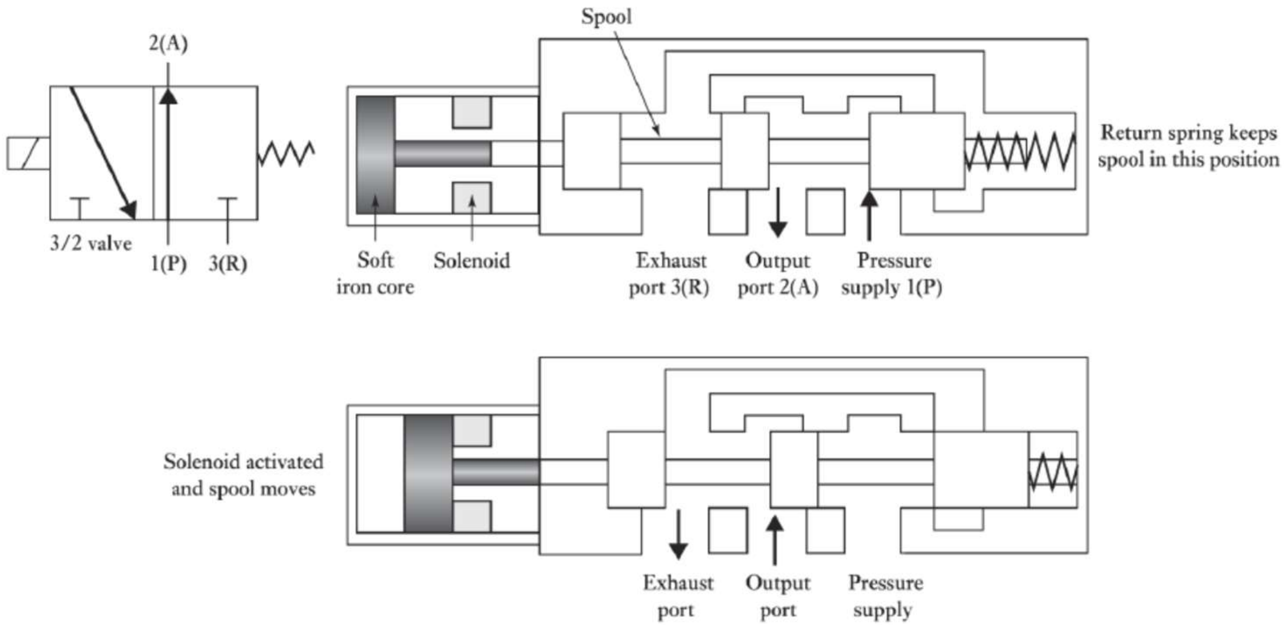
Valves Actuation Symbols

- Symbols of Valve actuation: indicate the various ways the valves can be actuated

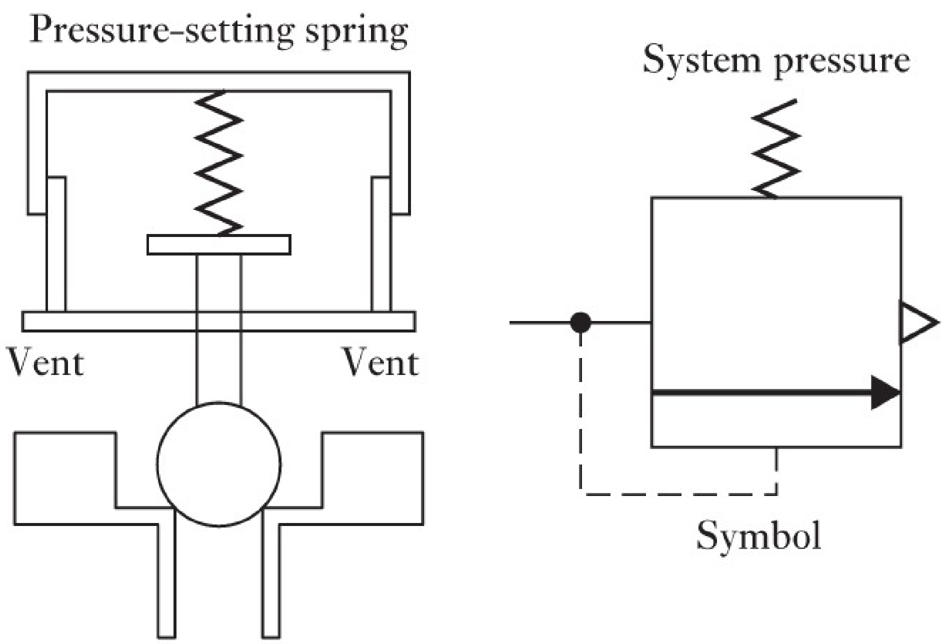


Solenoid-Operated Spool Valve

- The valve is actuated by a current passing through the solenoid and return to its original position by spring



Pressure Control Valve

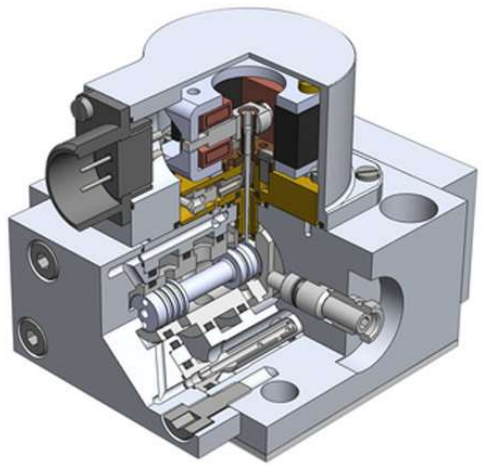


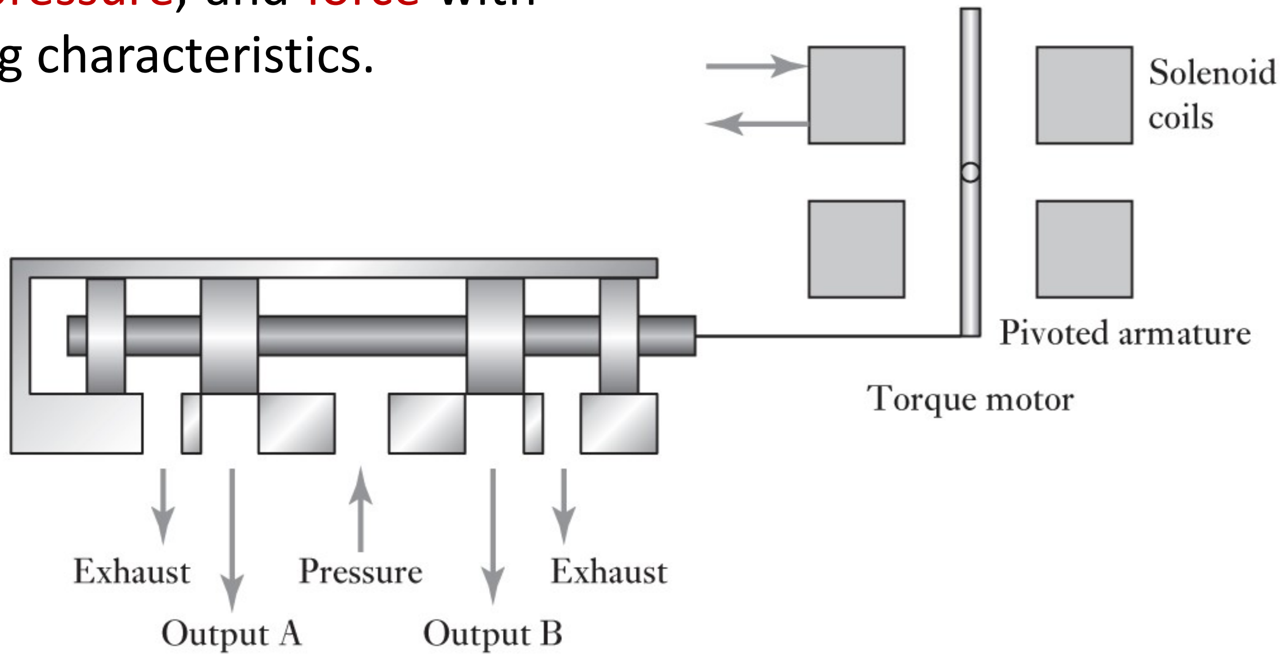
Three main types:

- Pressure limiting valve: used to limit the pressure in a circuit to below some value.
- Pressure regulation valve: used to control the operating pressure in a circuit and maintain it at constant value.

Servo Valves

An electrohydraulic servo valve is an electrically operated valve that controls how hydraulic fluid is sent to an actuator. Servo valves are often used to control powerful hydraulic cylinders with a very small electrical signal. Servo valves can provide precise control of position, velocity, pressure, and force with good post movement damping characteristics.



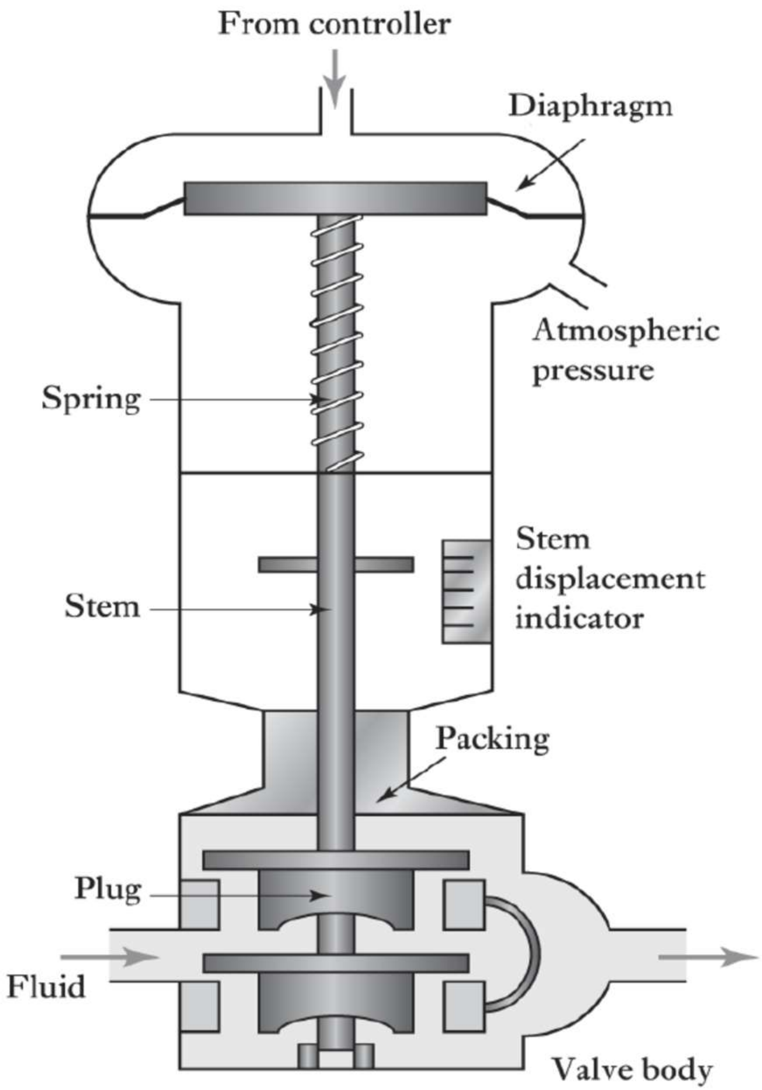


Process Control Valve

- Used to control the fluid flow rate
- A common form of pneumatic actuator used with process control valve is the diaphragm actuator.
- The diaphragm is made of rubber which sandwiched in it is centre between two circular steel discs.

Process Control Valve

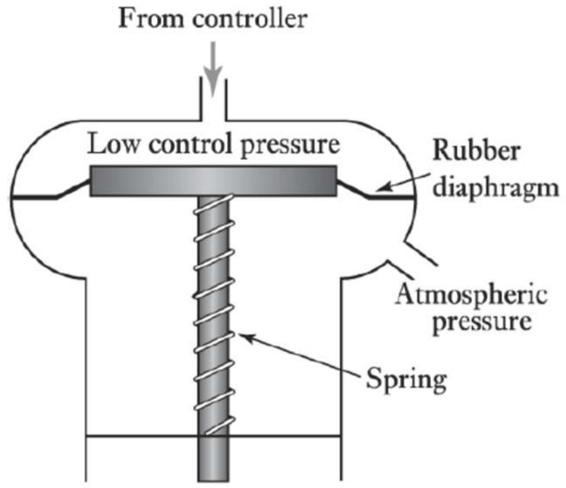
- Figure shows a cross section of valve for the control of rate of flow of a fluid.
- The plug restricts the fluid flow and so its position determines the flow rate.

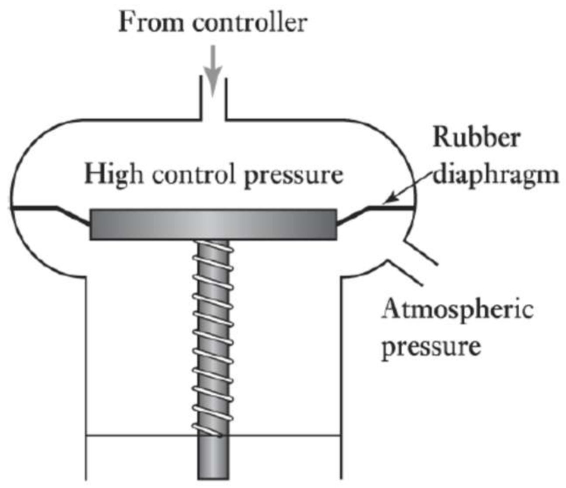


Process Control Valve

- The effect of changes in the input pressure is to move the central part of the diaphragm. The force F on the shaft is the force that acting on the diaphragm= P x A
  - P is the gauge pressure =Control pressure - atmospheric pressure
  - A is the diaphragm area

The restoring force is provided by spring, so $kx = PA$





<u>Question:</u> Attempt to design a spring for a process control valve considering the above information.

Part 4

Design of pneumatic systems

Design of pneumatic systems

Materials:

End caps, piston, mountings:

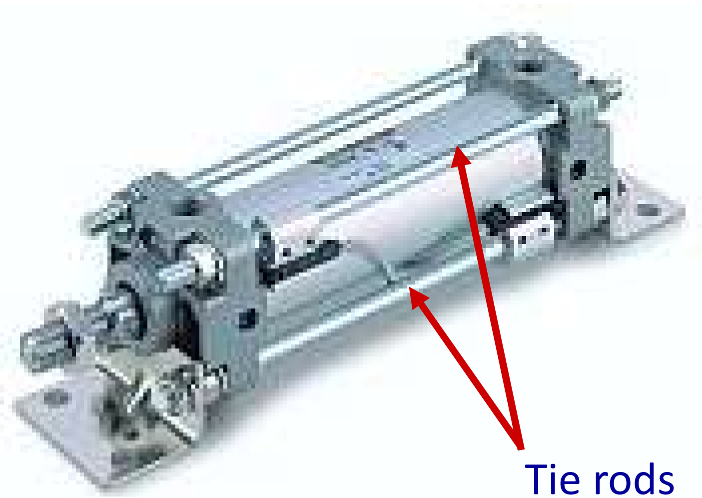
- Steel
- Cast iron
- Light alloy
- Brass

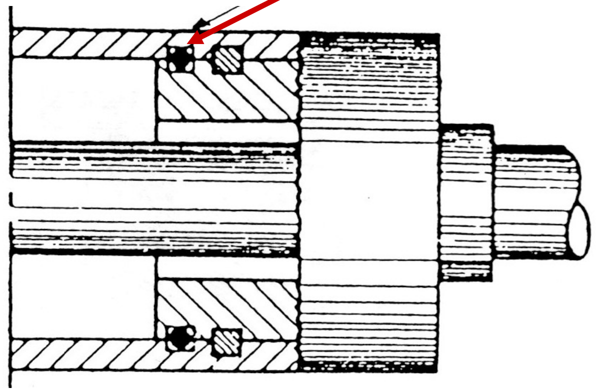
Cylinder barrel: Need to consider pressure and corrosion due to condensation in air

- Steel
- Light alloy
- Brass
- Copper

Design of pneumatic systems

End cover fixings:

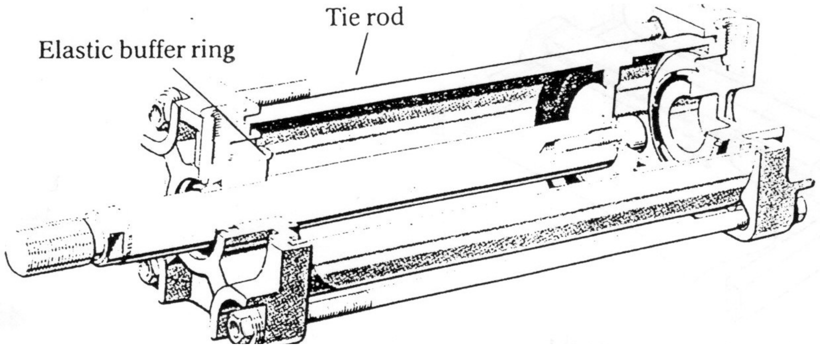




Cushioning

Collision of piston into end cover could cause damage so "cushioning" is necessary (relevant to the group D&M project)

1. Buffer ring cushioning



2. Pneumatic cushioning

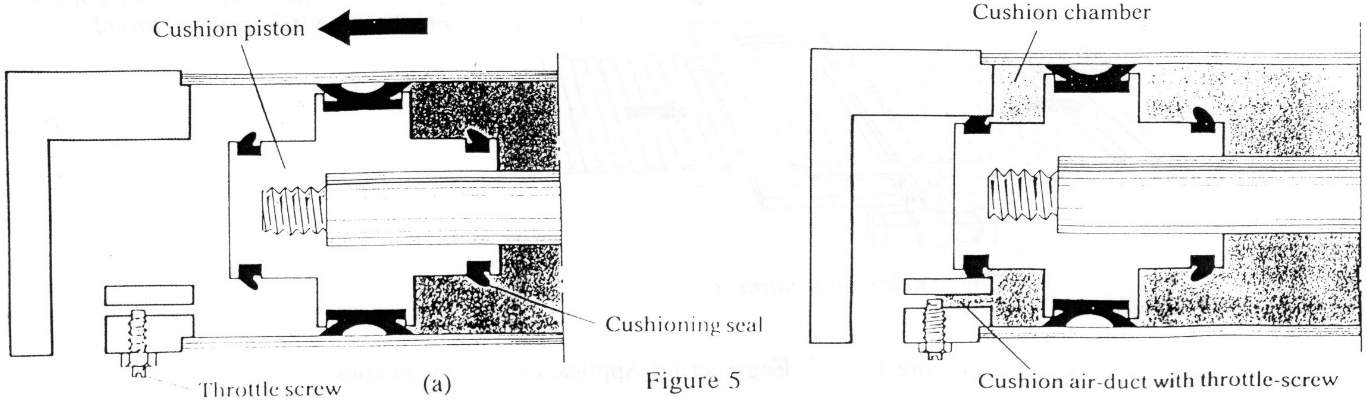
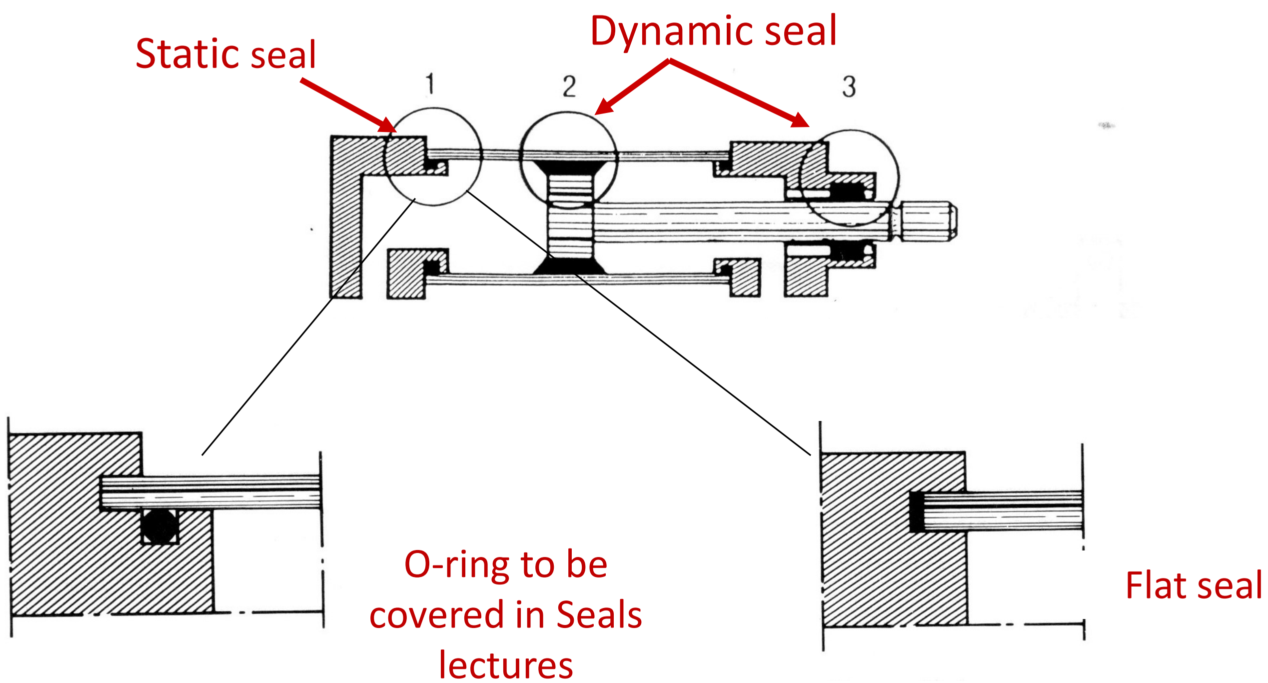


Figure 5

Design of pneumatic systems

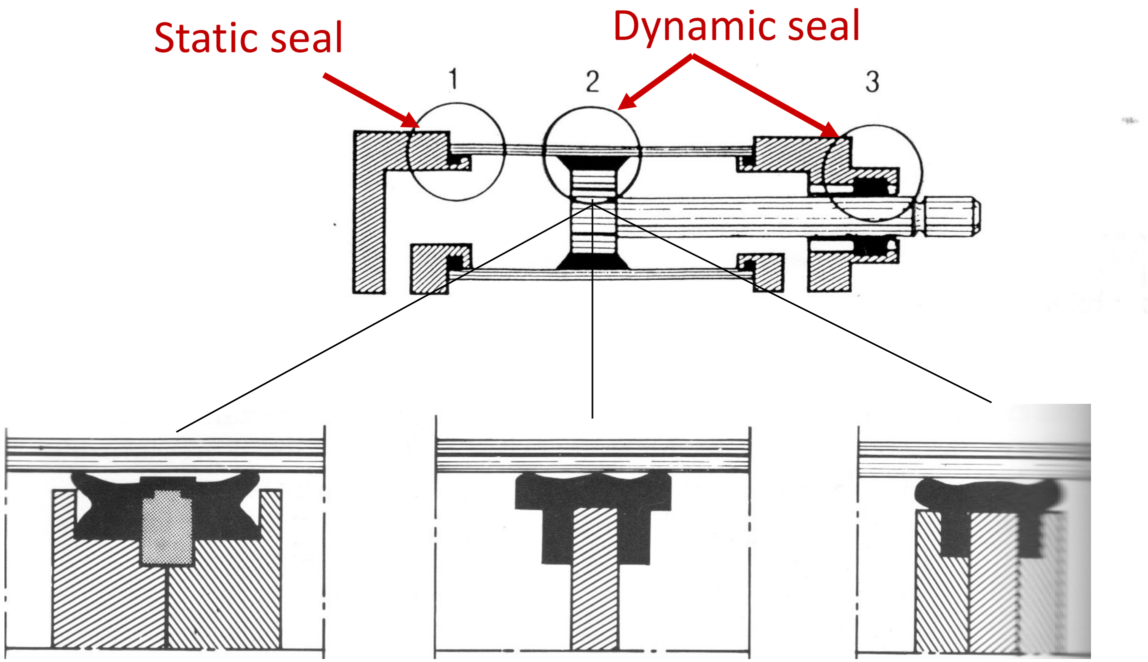
Cylinder barrel sealing (1): Prevent air from leaking out of barrel



- **O-ring is typical & commonly used solutions**
- Static seals

Design of pneumatic systems

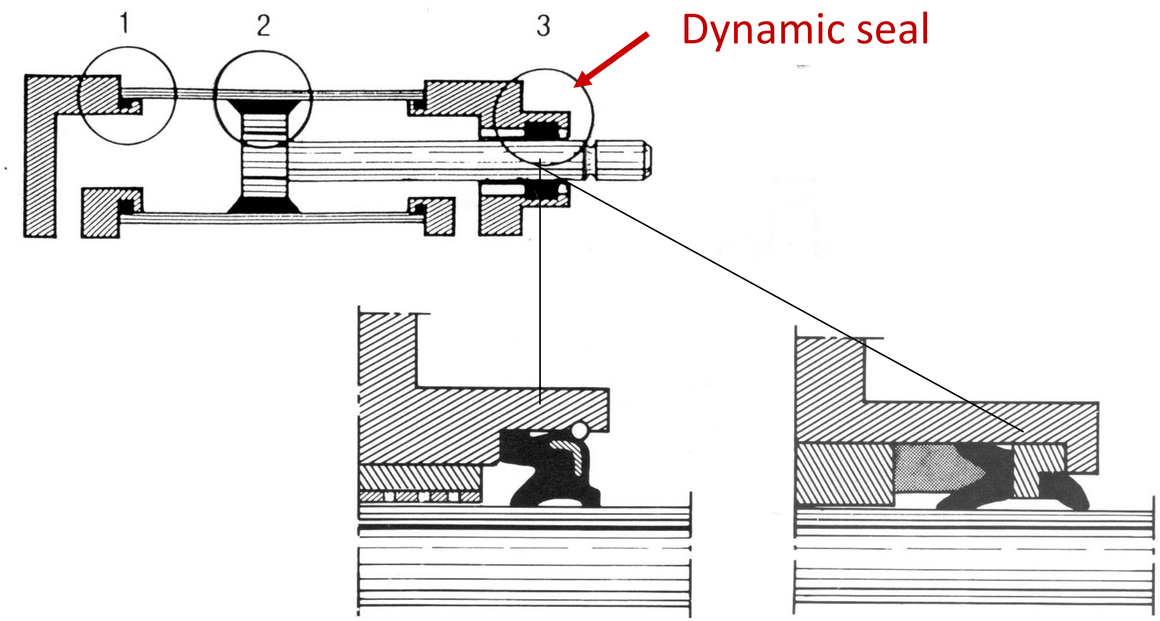
Piston sealing (2): Prevent air from leaking between chambers



- Dynamic seals
- U or V shaped with lip to seal against barrel while moving

Design of pneumatic systems

Piston rod sealing (3): Prevent air from leaking from end cover and wipe rod to stop dirt ingress



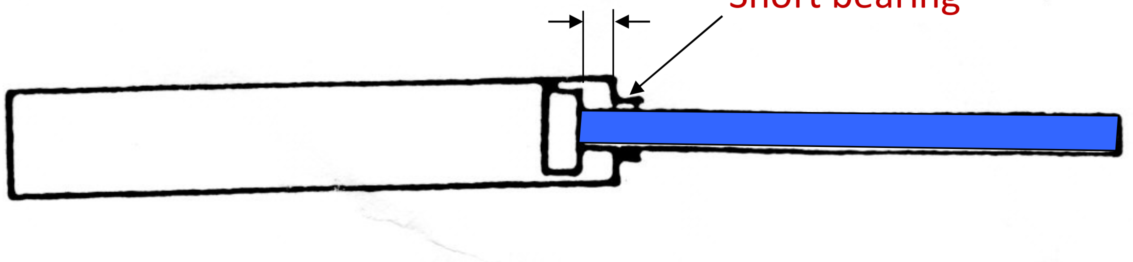
One Piece

Two Piece

- Dynamic seals
- One or two piece designs available

Design of pneumatic systems

Piston rod: Support required



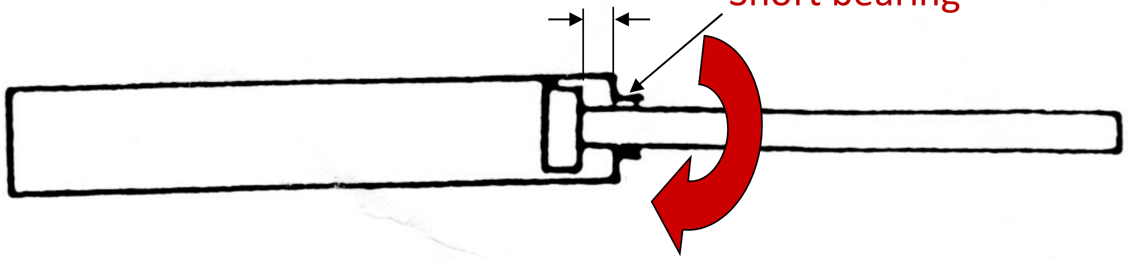
- Typically made from steel with hard chrome finish
- Protects from corrosion
- Provides smooth finish in contact with piston rod seal
- Reduce mass by making piston rod tubular

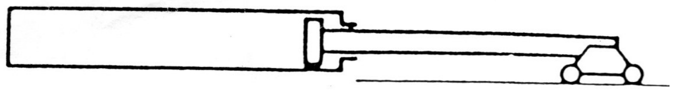
Design of pneumatic systems

Piston rod: Methods of support

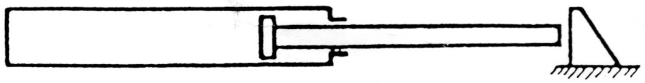
Minimal distance between bearing and full extension

Short bearing





End support to piston rod



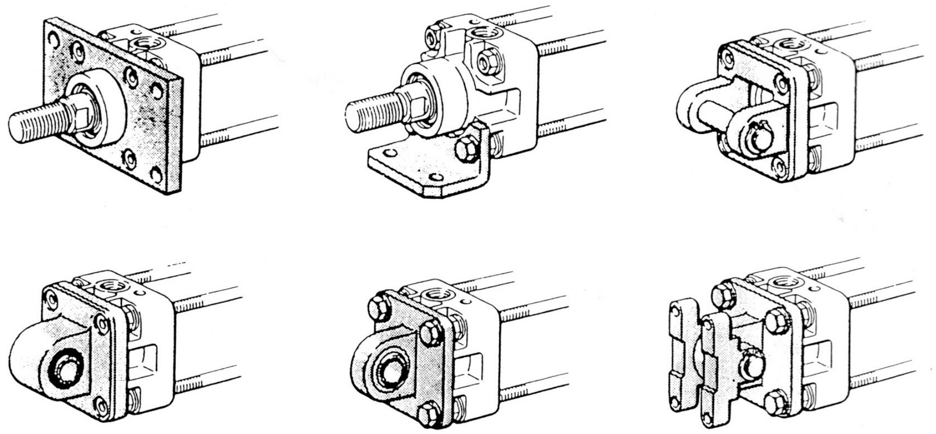
Limit travel of piston rod

Consider **buckling failure** if piston rod is long and forces are high

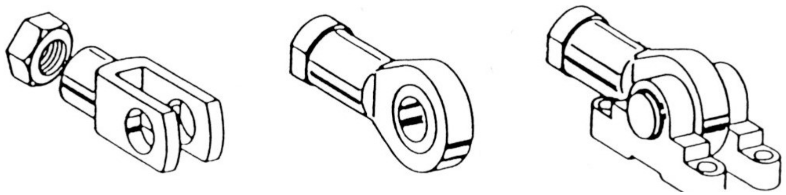
Lengthen bearing

Design of pneumatic systems

Mountings:



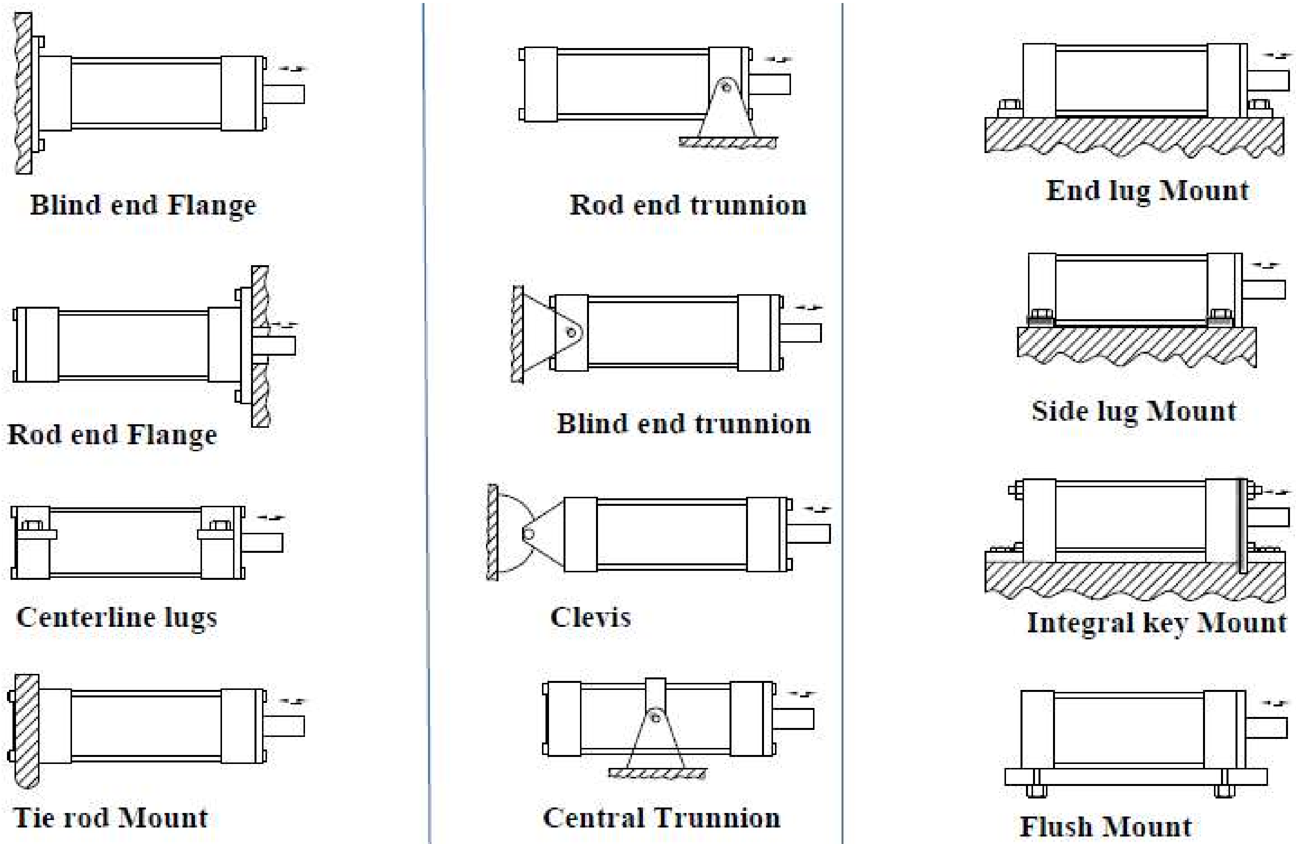
End cover fixings often utilised



Clevis/trunnion used to ease alignment of piston rod

Design of pneumatic systems

Mountings: a few more examples



a) Fixed centerline mountings

a) Pivoted centerline mountings

a) Fixed noncenterline mountings

Design considerations for the pneumatic system of the transfer station project

- Suitable type of cylinder?
- Selection of materials
- Methods for fixing of endcaps and assembly of cylinder
- Sealing methods?
- Is cushioning a necessary feature?
- Mounting of cylinder?
- Any necessary calculations?

Revision Questions

a) Differentiate between single acting and double acting actuators.
b) What are the typical components of a hydraulic power system?
c) What is the main function of the accumulator in a hydraulic power system?
d) Mention the three types and function of pressure control valves.
e) What are the differences between single seated and double seated pressure control valve.

f) A hydraulic cylinder to be used to move a payload in a manufacturing operation through a distance of 300 mm in 30 s. If a force of 75 kN is required to move the work piece and the cylinder has a piston diameter of 200 mm:

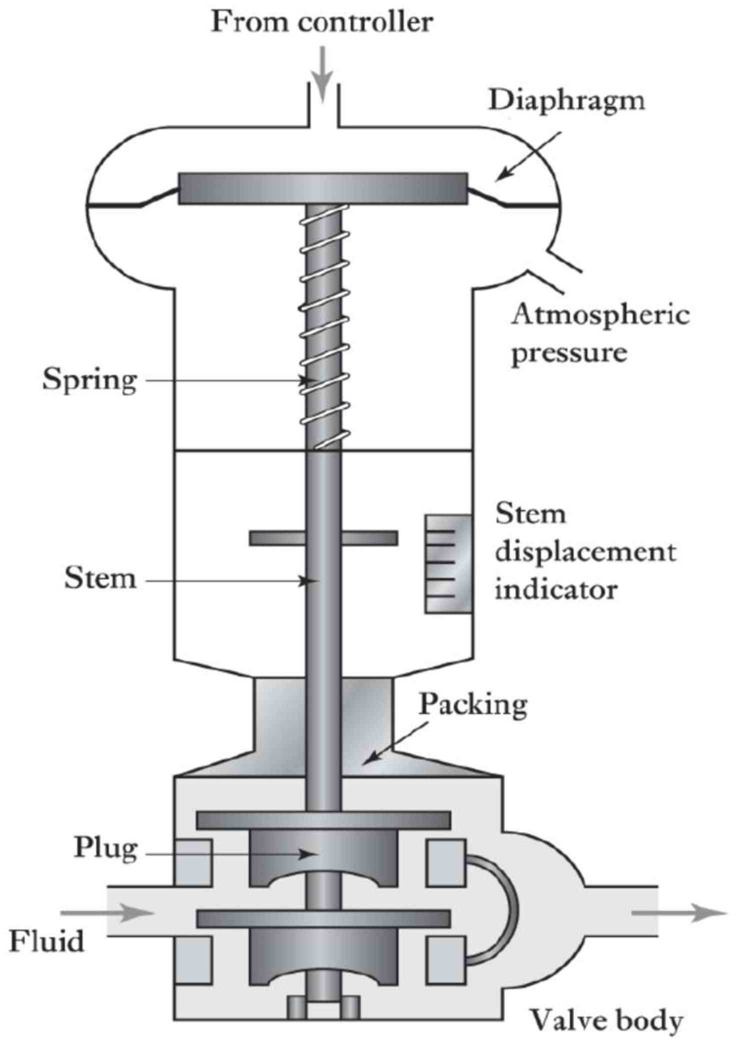
- What is the required working pressure?
- What is the hydraulic liquid flow rate?
- What is the speed of the piston?
- If a restoring piston is to be used, what is the sufficient spring stiffness?

Revision Questions

In the process control valve shown in the Figure, design the appropriate spring with a stiffness K in order to give a sufficient restoring force given the following data:

- Control pressure = 800 kPa
- Atmosphere pressure = 101.325 kPa
- Diameter of the diaphragm = 100 mm
- The stroke of the piston = 50 mm

If the time taken for the movement of the piston is 10 seconds, what is flow rate of the liquid?



Hint:

The restoring force is provided by spring, so $kx = PA$

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Pneumatic and Hydraulic Systems

End of Session