Mechatronic Actuators

Lecture 2

Comparison of actuators, typical uses

Pneumatic actuators

What are pneumatic actuators?

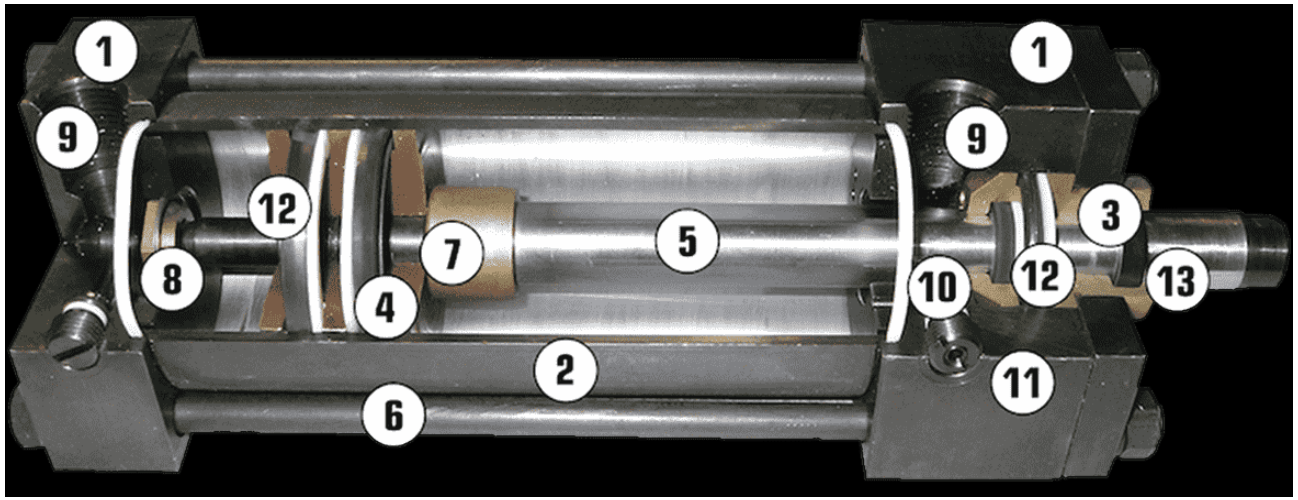
- Dictionary.Com gives the following definition of pneumatic operated by air or by the pressure or exhaustion of air http//dictionary.reference.com/browse/pneumatic
- A pneumatic actuator is a transducer that converts energy (typically from compressed air) into motion

Types of Pneumatic Actuators?

- Tie Rod Cylinders (linear actuators)
- Rotary Actuators (air motors)
- Grippers
- Pneumatic Control Valve

Tie Rod Cylinders

- Provides linear motion from compressed air
- Single or Double Action



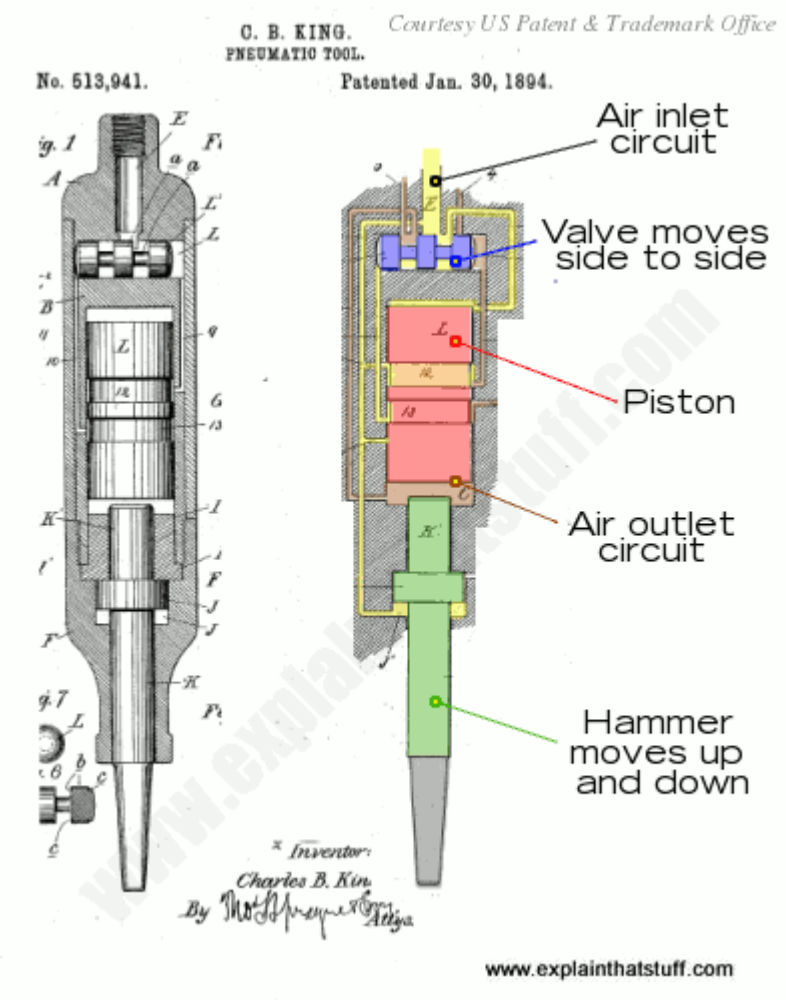
Working Principles (Linear Pneumatic Actuators)

- Convert pneumatic energy into mechanical energy to produce work
- There is a hollow cylinder with a piston inside.
- Air pushes the piston causing motion in the cylinder, the piston is connected to an external rod that provides a means to use the motion.
- The actuator can be either single or double action either a spring etc. returns the actuator or air will return it via multiple ports.
- http//www.ifps.org/Education/WhitePapers/PneumaticCylinders.htm

Linear Actuator Application

- Air compressor/Jack hammer related to the tie-rod cylinder

https://www.youtube.com/watch?v=0Deft6F-6N4



Rotary Actuator (air motor)

4 Types:

- Rotary Vane
- Gear
- Turbine
- Piston

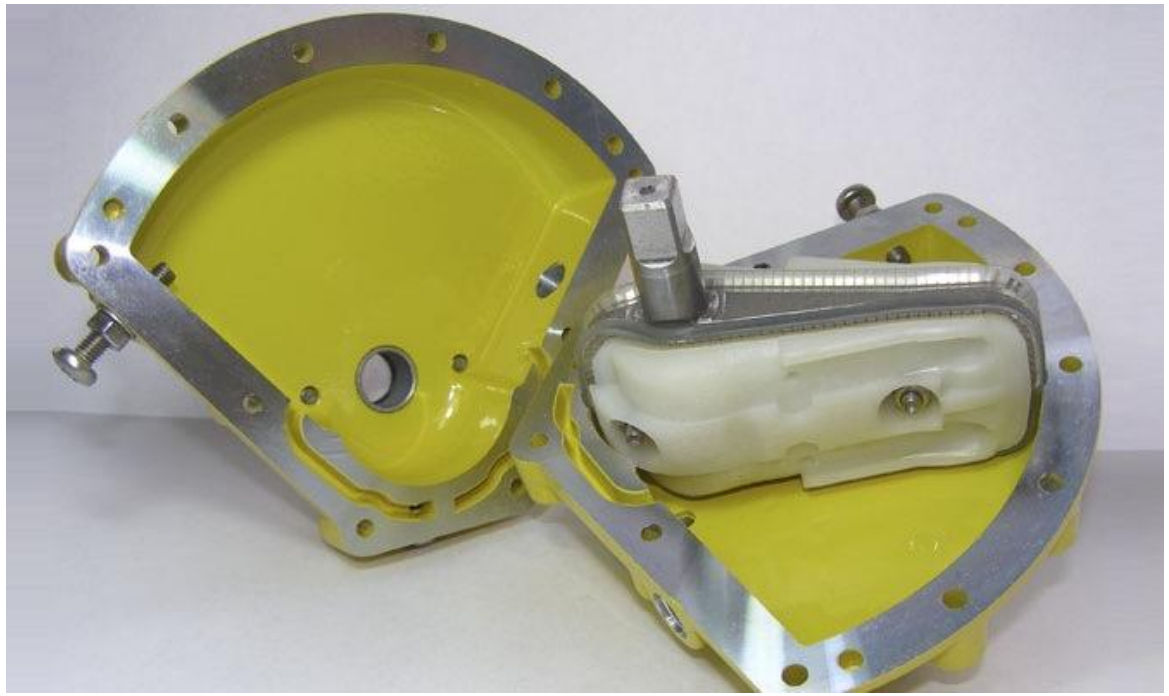
www.tdi-turbotwin.com

Working Principles (Rotary Pneumatic Actuators)

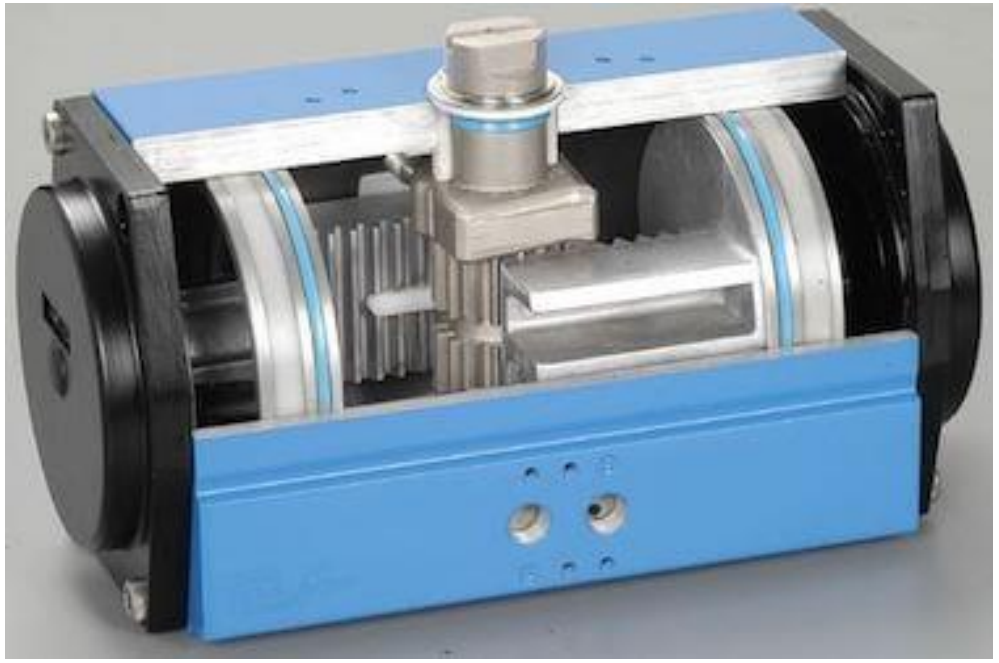
- Rotary actuators are used to convert potential pneumatic energy into mechanical energy.
- Rotary actuators produce torque
- Commonly called air motors
- In most cases rotary actuators are not chosen for their efficiencies, but for their power, speed and torque.

http//www.ifps.org/Education/WhitePapers/PneumaticCylinders.htm

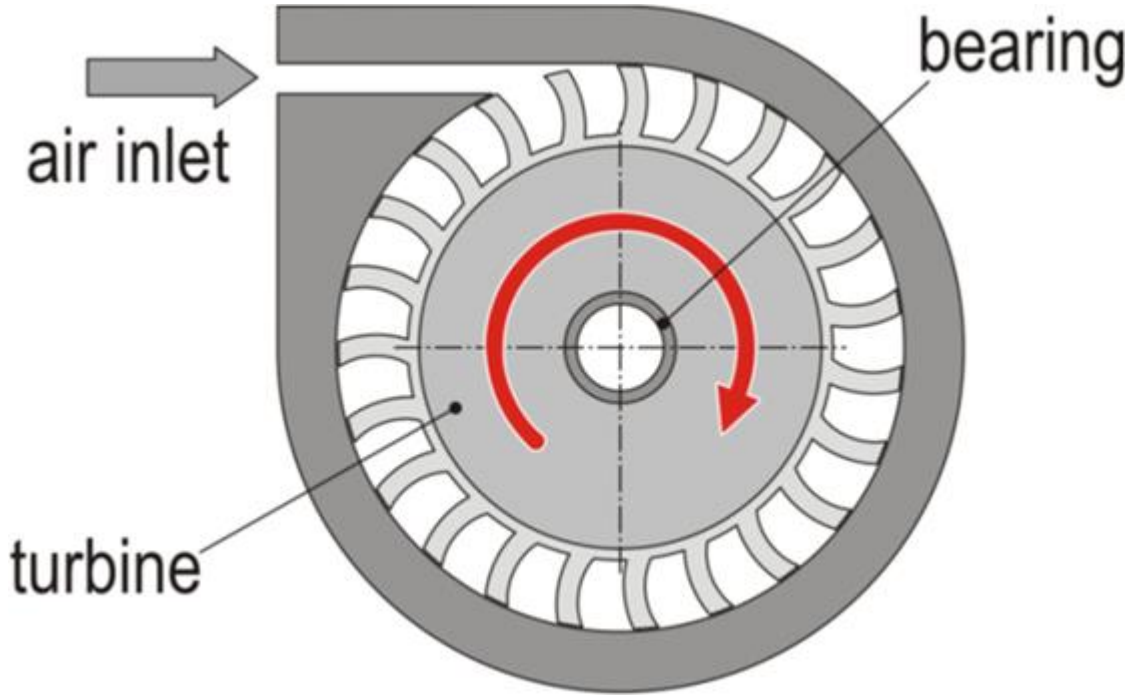
Rotary vane pneumatic actuator

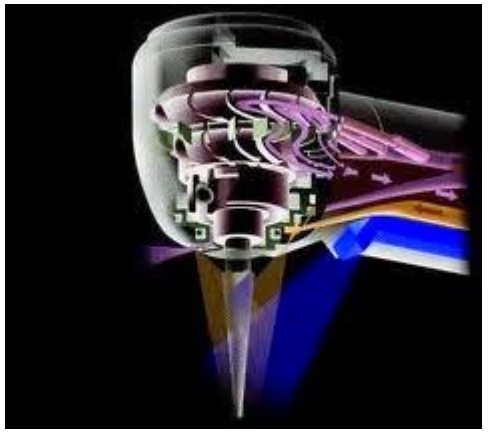


Gear rotary actuator

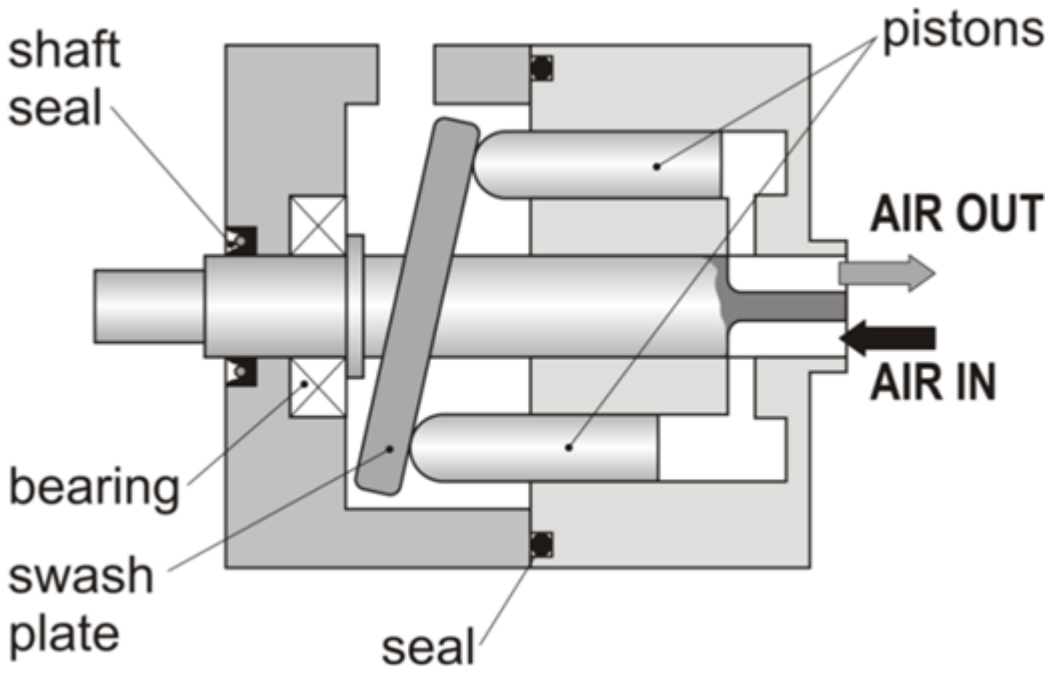


Turbine





Piston



Pneumatic Gripper

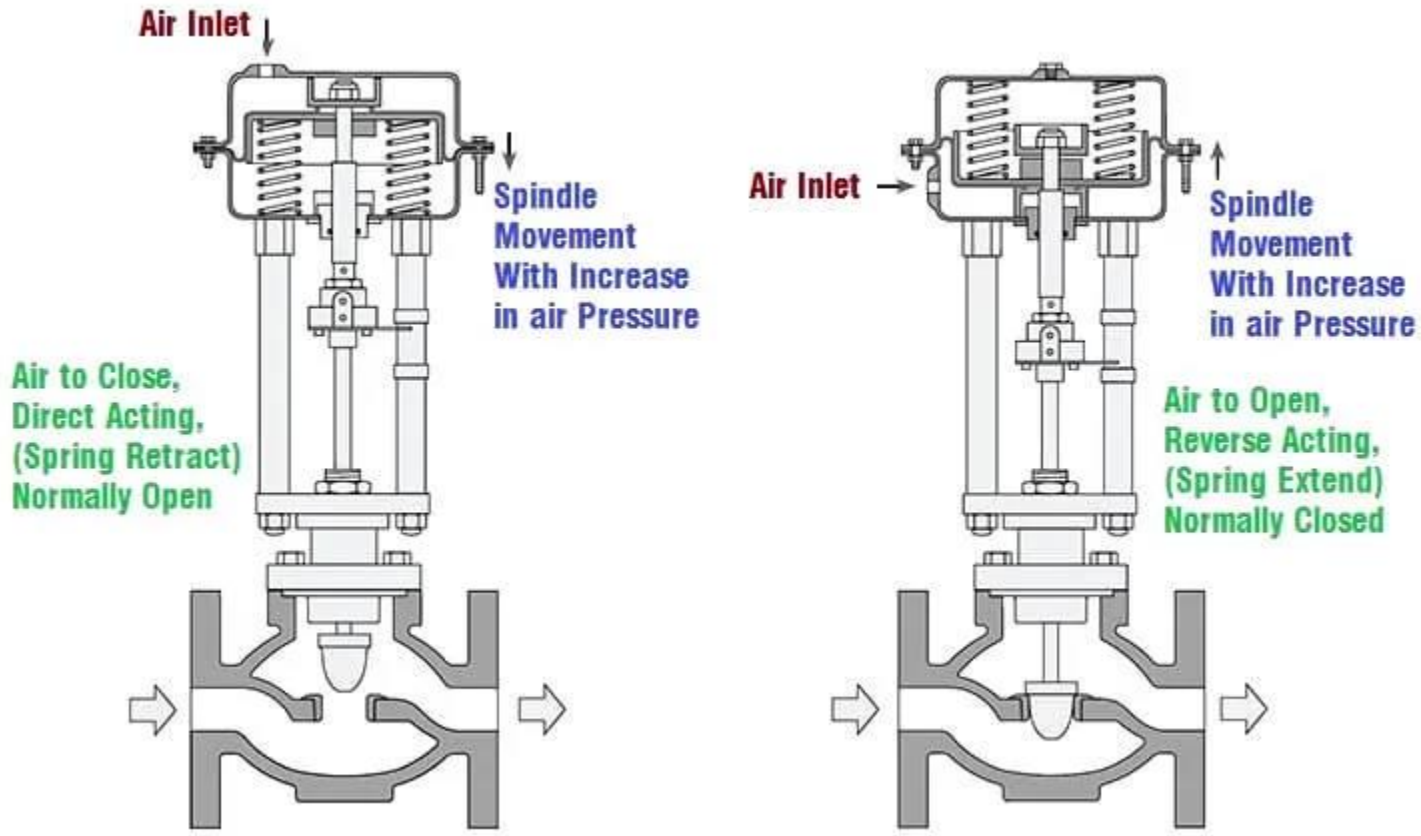
- Involves linear or angular motion
- Often used to pick and place objects
- Generally has fully open and fully closed settings and does not have control to go to intermediate positions

Working Principles (Grippers)

- Converts potential pneumatic energy into mechanical energy
- Creates either linear or angular motion of gripper fingers
- Forces are proportional to pressure and area.

Pneumatic Control Valve

- Uses air pressure to open and close the valve.
- Used in conjunction with an electronic controller



Working Principles (Control Valve)

- Operates by a combination of force from the air and an opposing spring force. The actuator positions the control valve by transmitting its motion through the stem.

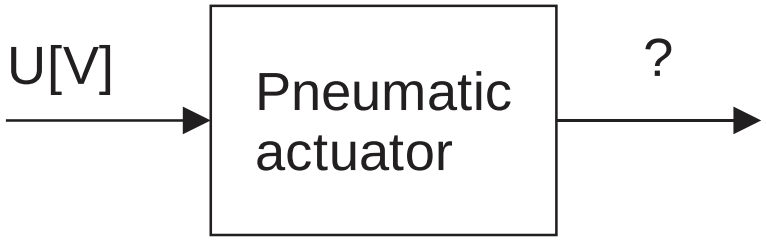
Major Specifications

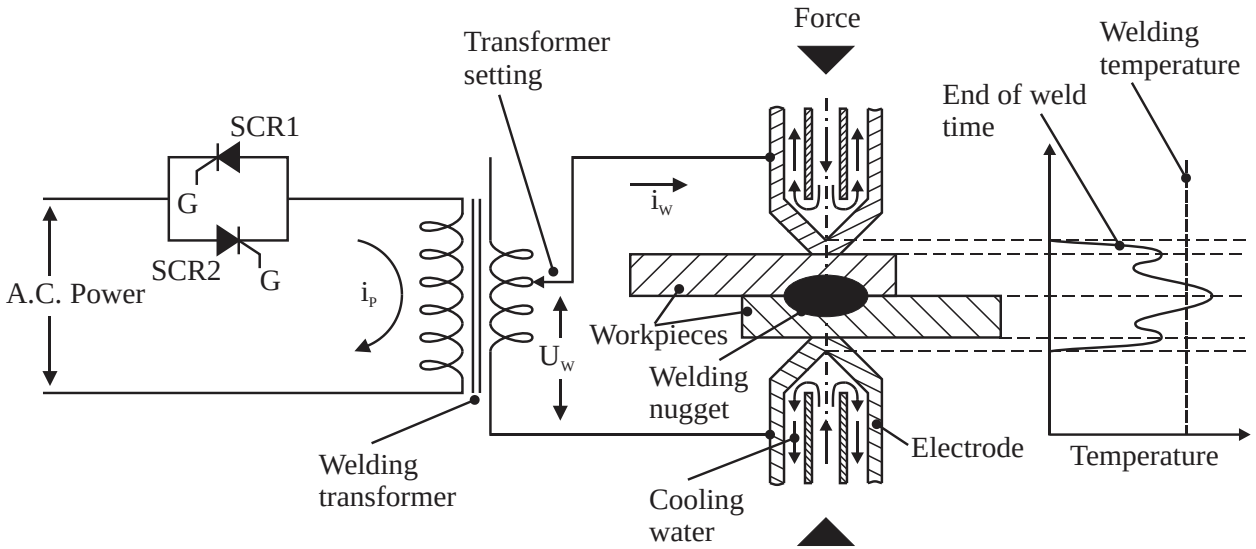
- Required Air Flow Rate
- Max Pressure/Required Pressure
- Capable Force
- Capable Torque
- Max RPM
- Linear Velocity

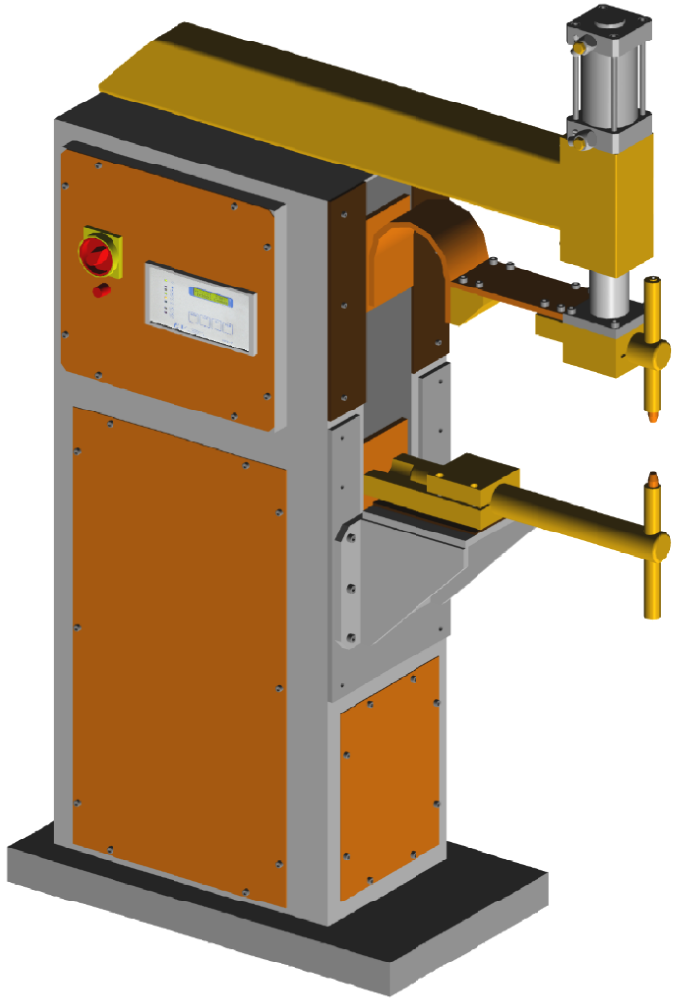
Limitations

- Compressibility of air makes movement and positioning imprecise
- Not capable of heavy work (250psi vs. 10,000 psi) (20bar vs 700bar)

Pneumatic actuator as part of a system



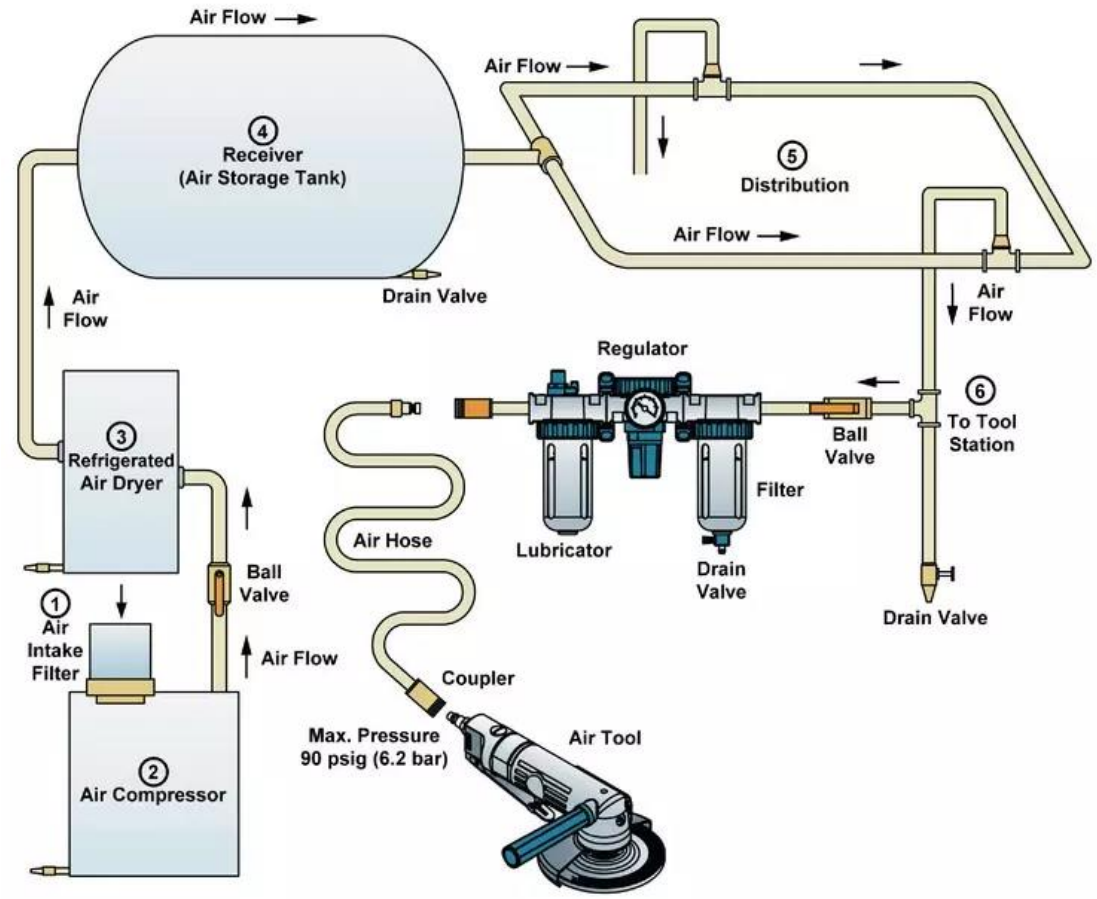




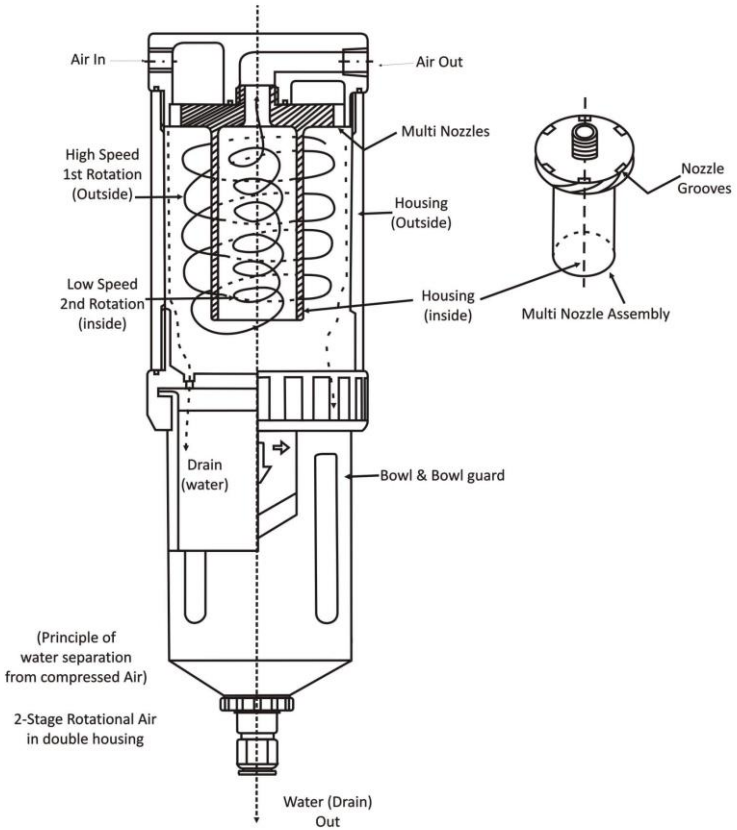
Cost of Pneumatic Actuators

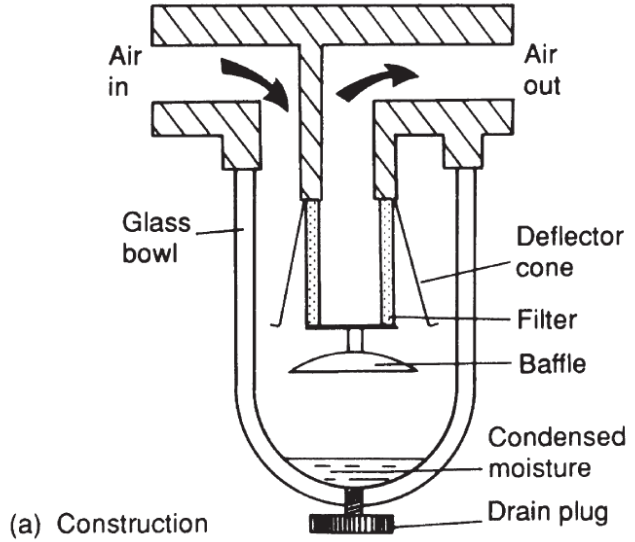
- Pneumatic actuators range from as low as 15 on up to tens of thousands of dollars depending on quality, size, application etc.

A pneumatic system

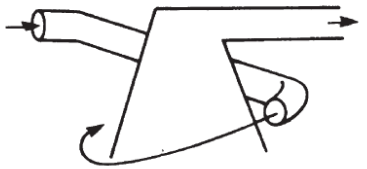


Dryer / Water separator

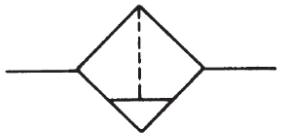




(a) Construction

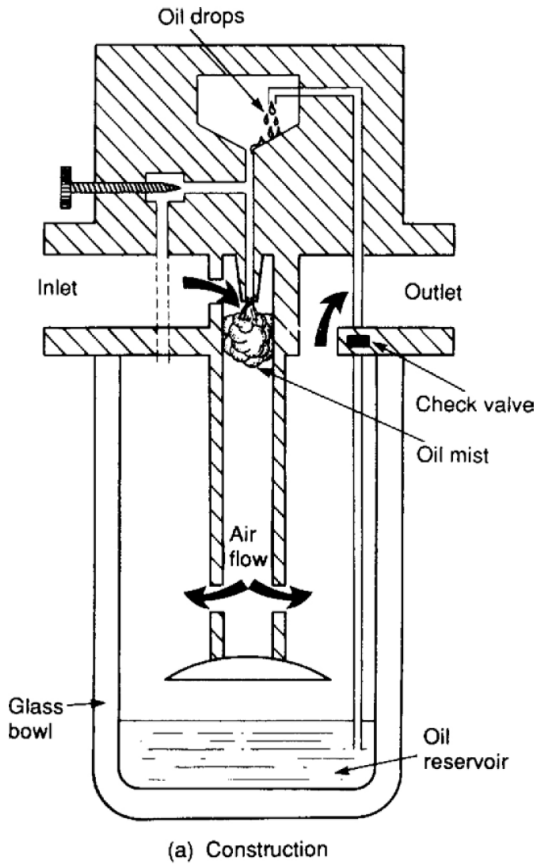


(b) Swirl introduced by deflector cone

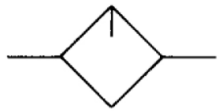


(c) Symbol

Lubrication



(a) Construction

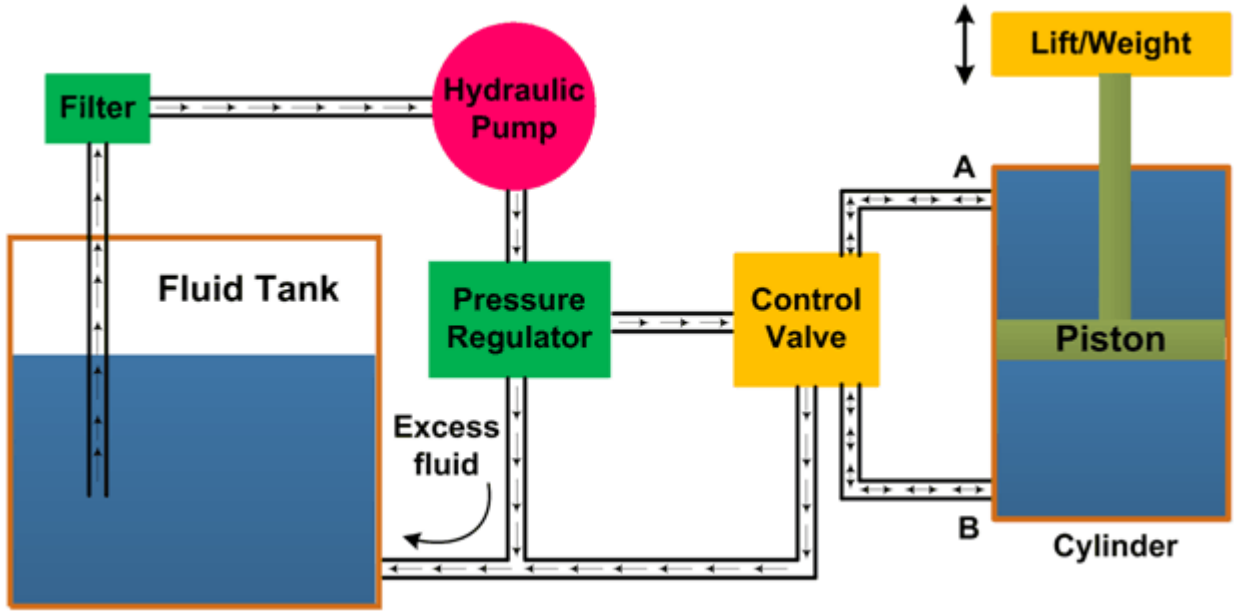


(b) Symbol for lubricator

Air supply parameters

Class	Particle size (μm)	Particle density (mg m^{-3})	Dew point (°C)	Oil content (mg m^{-3})	Typical application
1	0.1	0.1	–70	0.01	Paint spraying
2	1	1	–40	0.1	Process control and instrumentation
3	5	5	–20	1	Miniature solenoid valves
4	15	8	3	5	Standard factory pneumatics
5	40	10	7	25	Machine tools

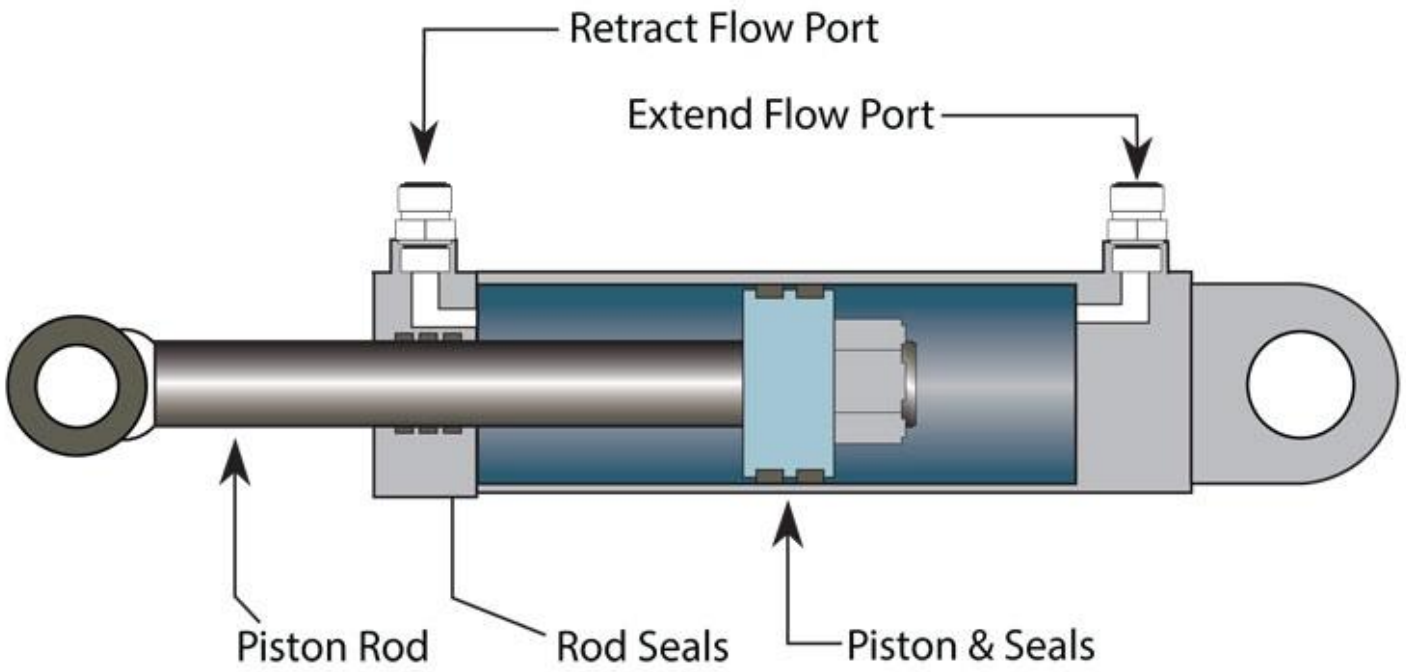
Hydraulic system



Hydraulic actuators

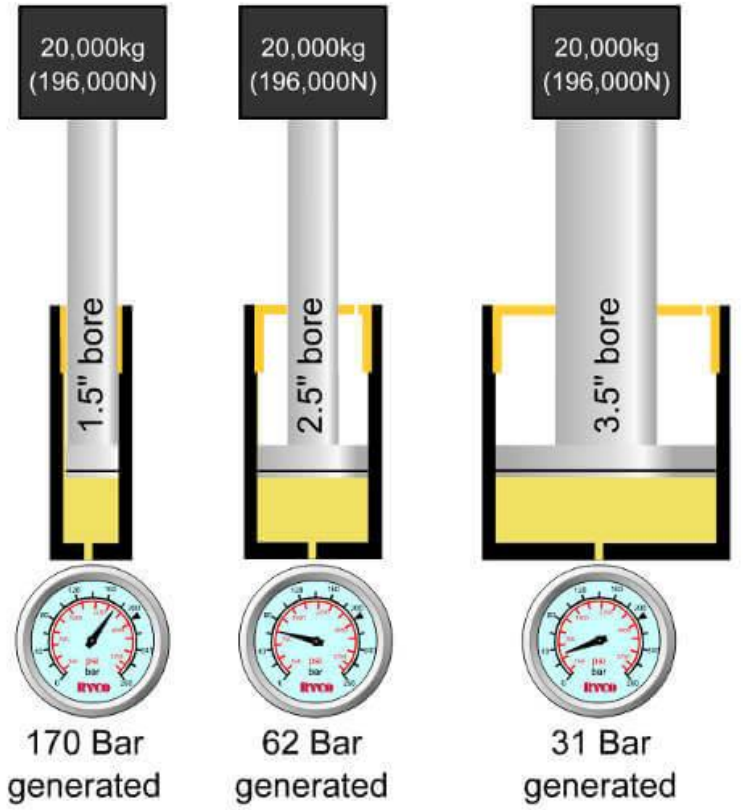
- Linear
- Rotational

Hydraulic cylinder



Pressure, size and force

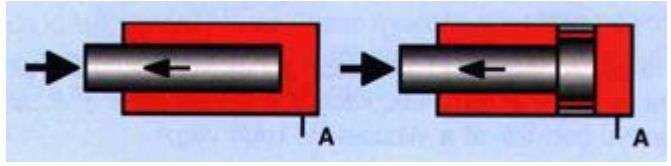
- Force needed
- Buckling

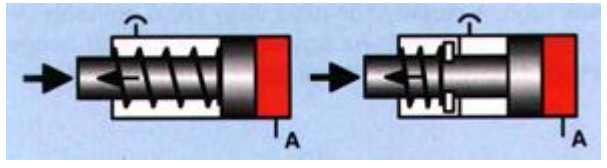


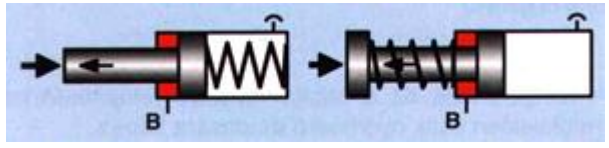
Cylinder types

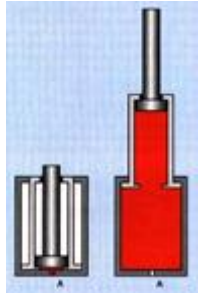
Single acting:

work can be done only in one direction



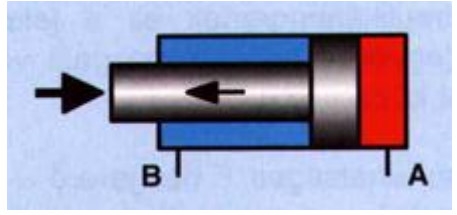


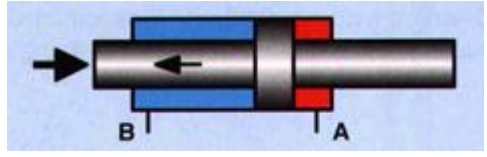


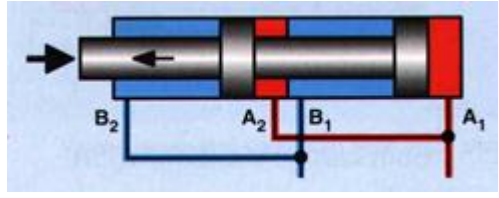


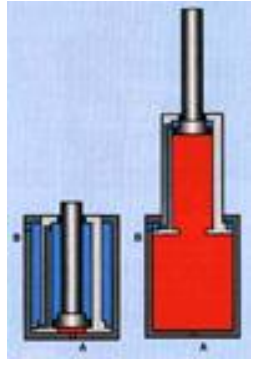
Double acting piston:

Work is done in both directions

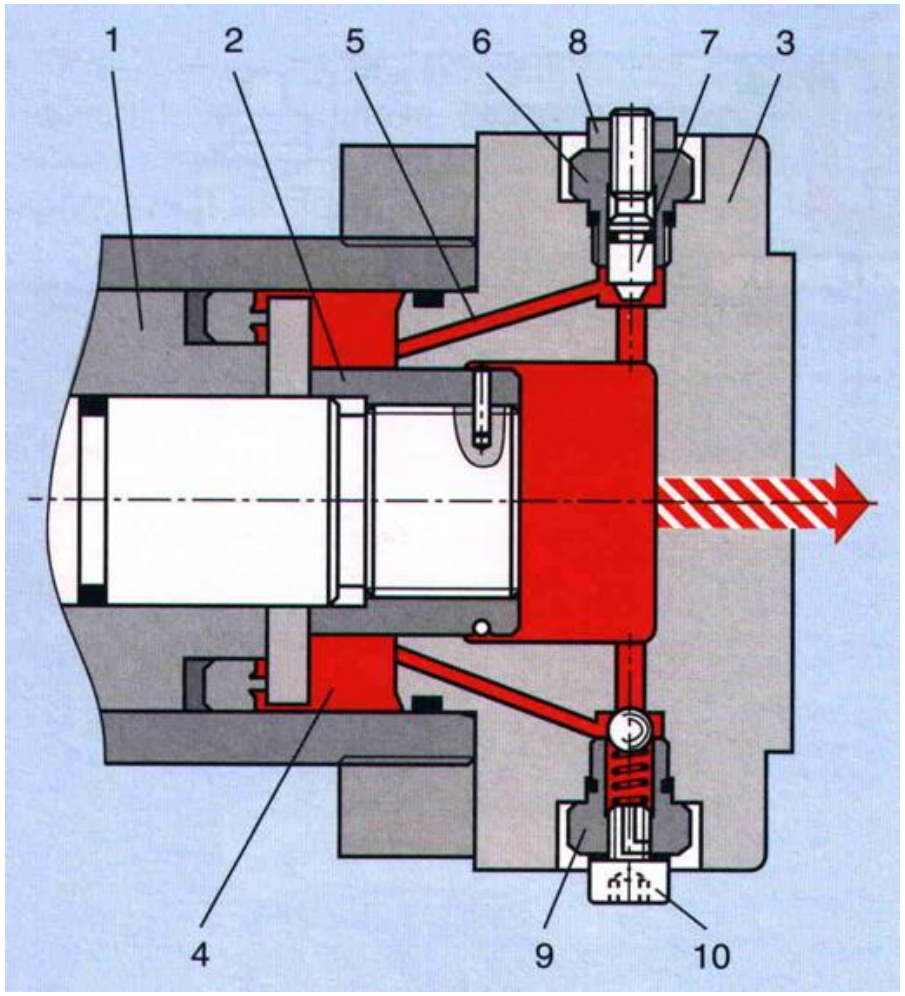








Cushioning of cylinders



Calculation of cylinders

$$F_{c_{\max}} = F_{L_{\max}} + F_F + F_1 \quad \Rightarrow \quad F_{C_{\max}} \approx F_{L_{\max}} + F_F$$

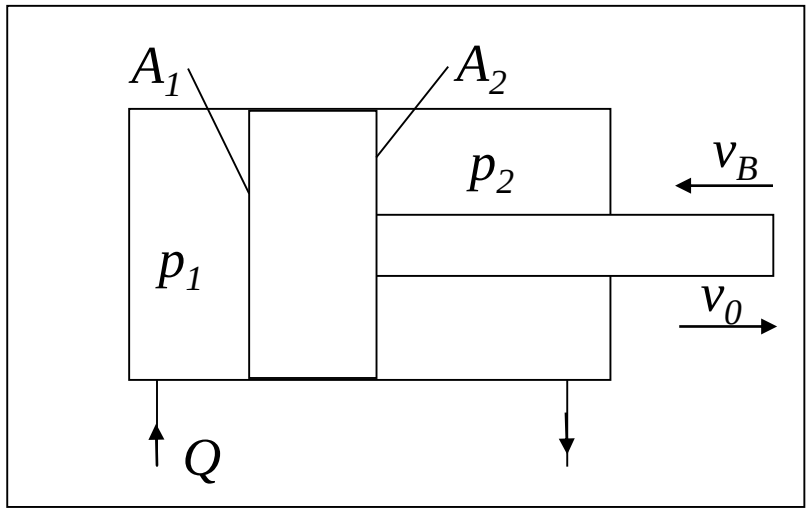
maximum load — friction forces — inertial forces (slow motion, can be often neglected)

Outward:

$$F_{C0} = A_1 p_1 - A_2 p_2$$

Backward:

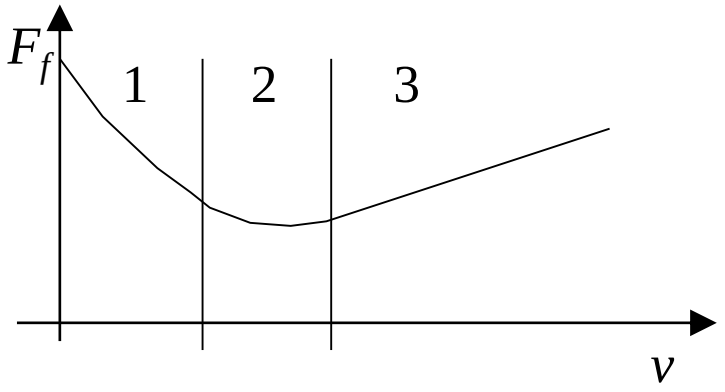
$$F_{CB} = A_2 p_2 - A_1 p_1$$



$$v_0 = \frac{Q}{A_1} \qquad v_B = \frac{Q}{A_2}$$

Friction

1. Stick-slip
2. Transition
3. Normal behaviour

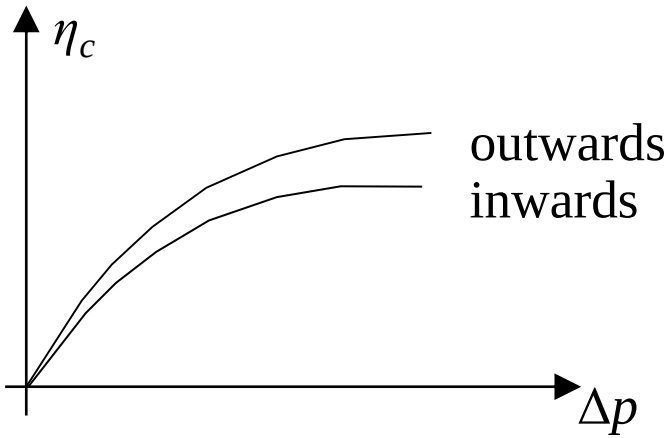


Hydraulic cylinders should be possibly operated in the 3rd region for smooth operation.

If the cylinder is new, the leakage losses are negligibly small so that:

$\eta_c = \eta_{mech}$

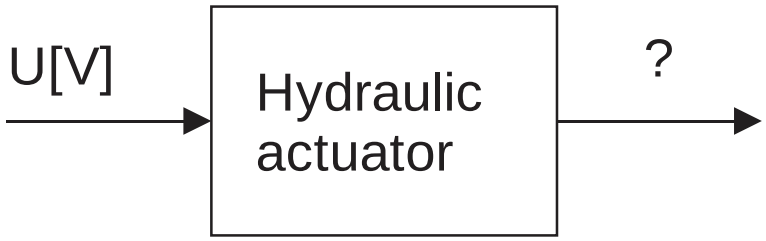
$$\eta_c = \frac{v \cdot F_L}{p_1 Q_1 - p_2 Q_2} = \frac{F_L}{p_1 A_1 - p_2 A_2}$$



$\eta_{c_{max}} = 0{,}85 - 0{,}92$

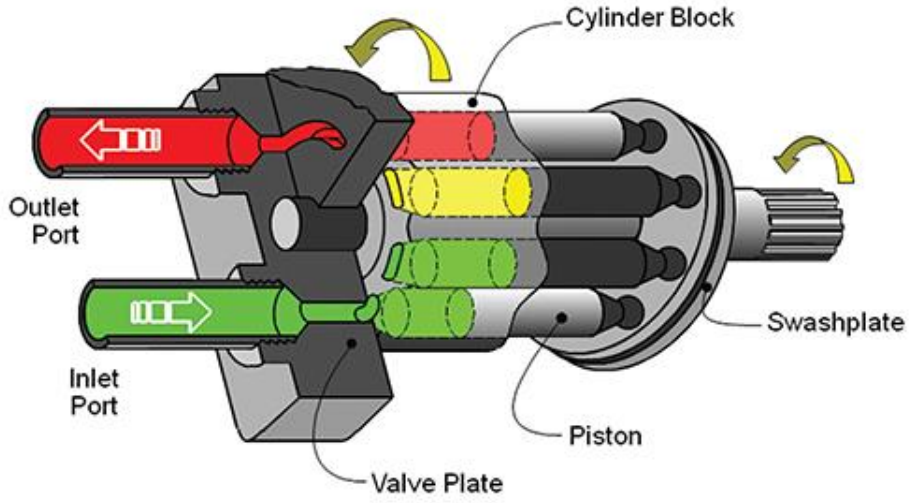
at higher pressures

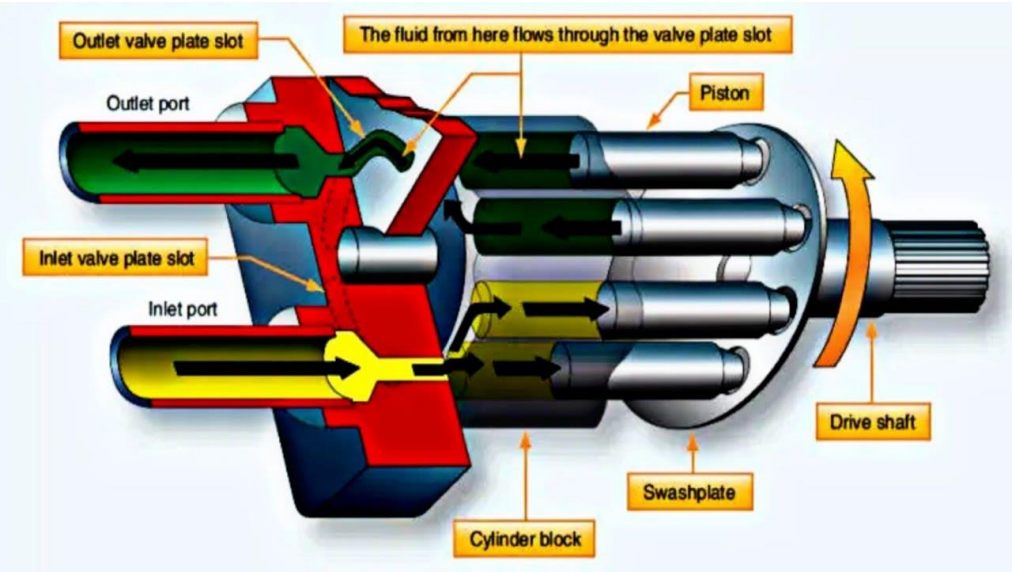
Hydraulic actuator as part of a system

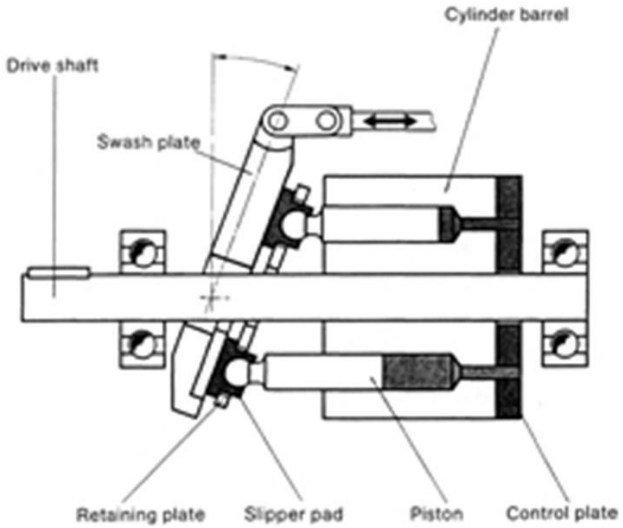


Typical applications

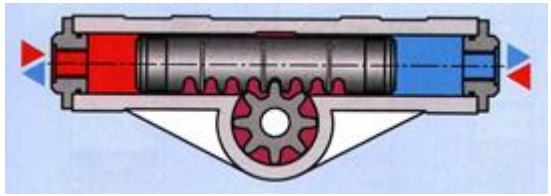
Swash plate hydraulic motor

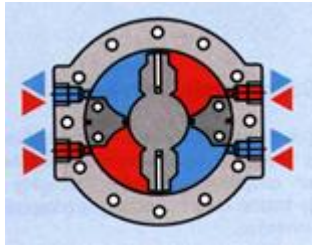


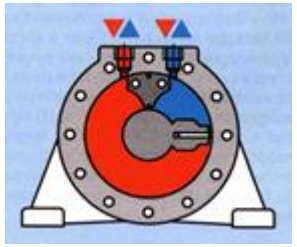


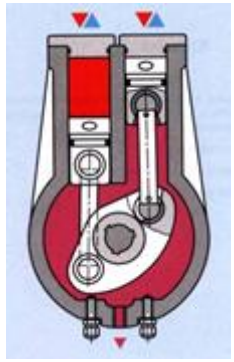


Similar types as in the case of pneumatics

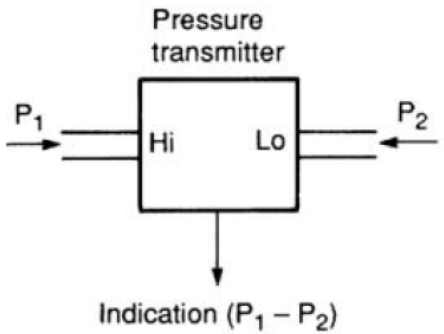




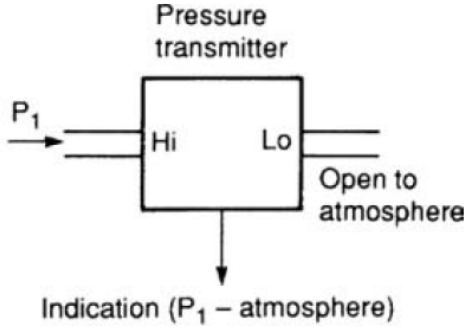




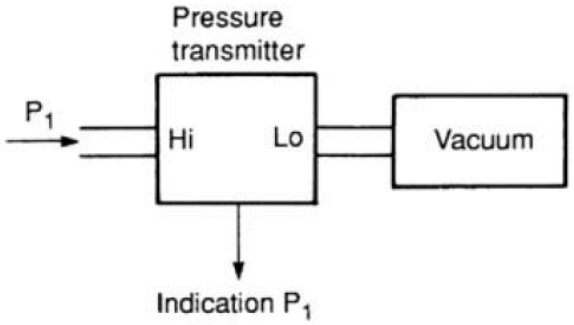
Pressure values



(a) Differential pressure

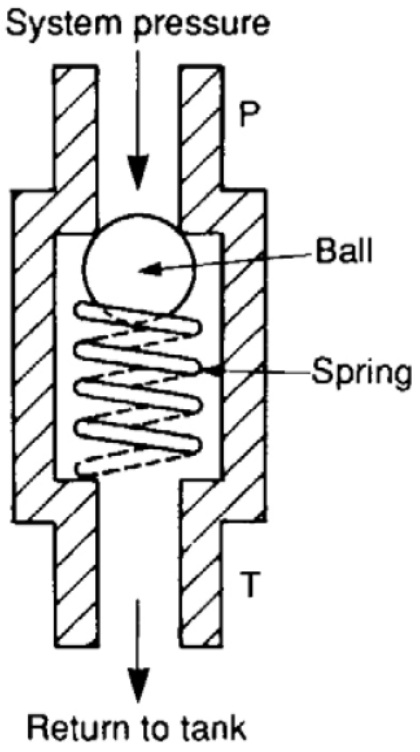


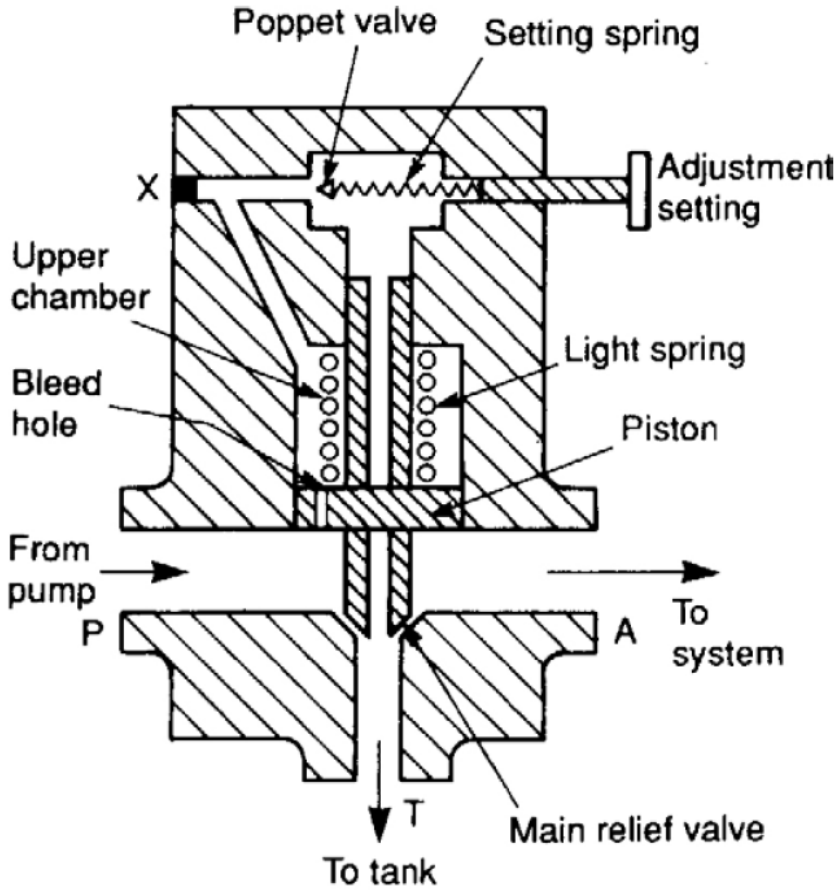
(b) Gauge pressure



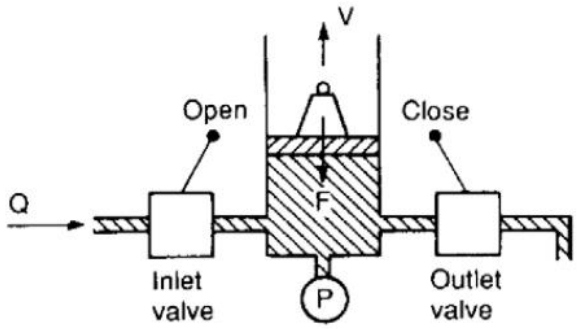
(c) Absolute pressure

Pressure control

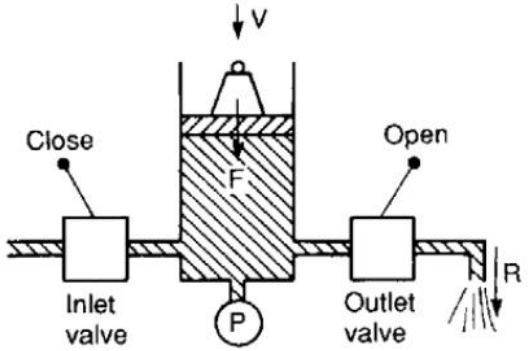




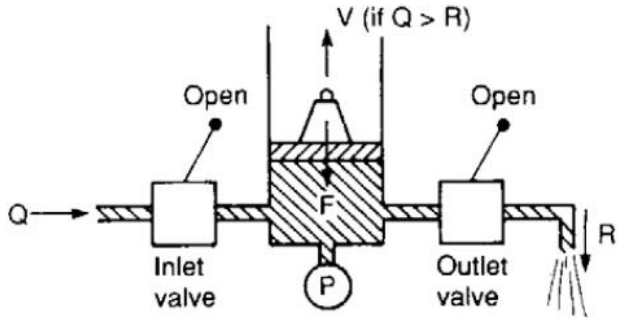
Dynamic phenomena



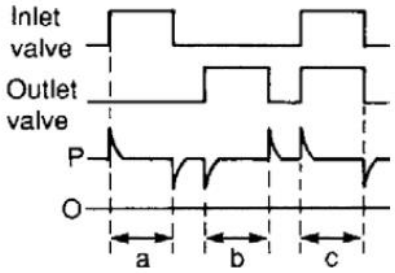
(a) Raising the load



(b) Lowering the load

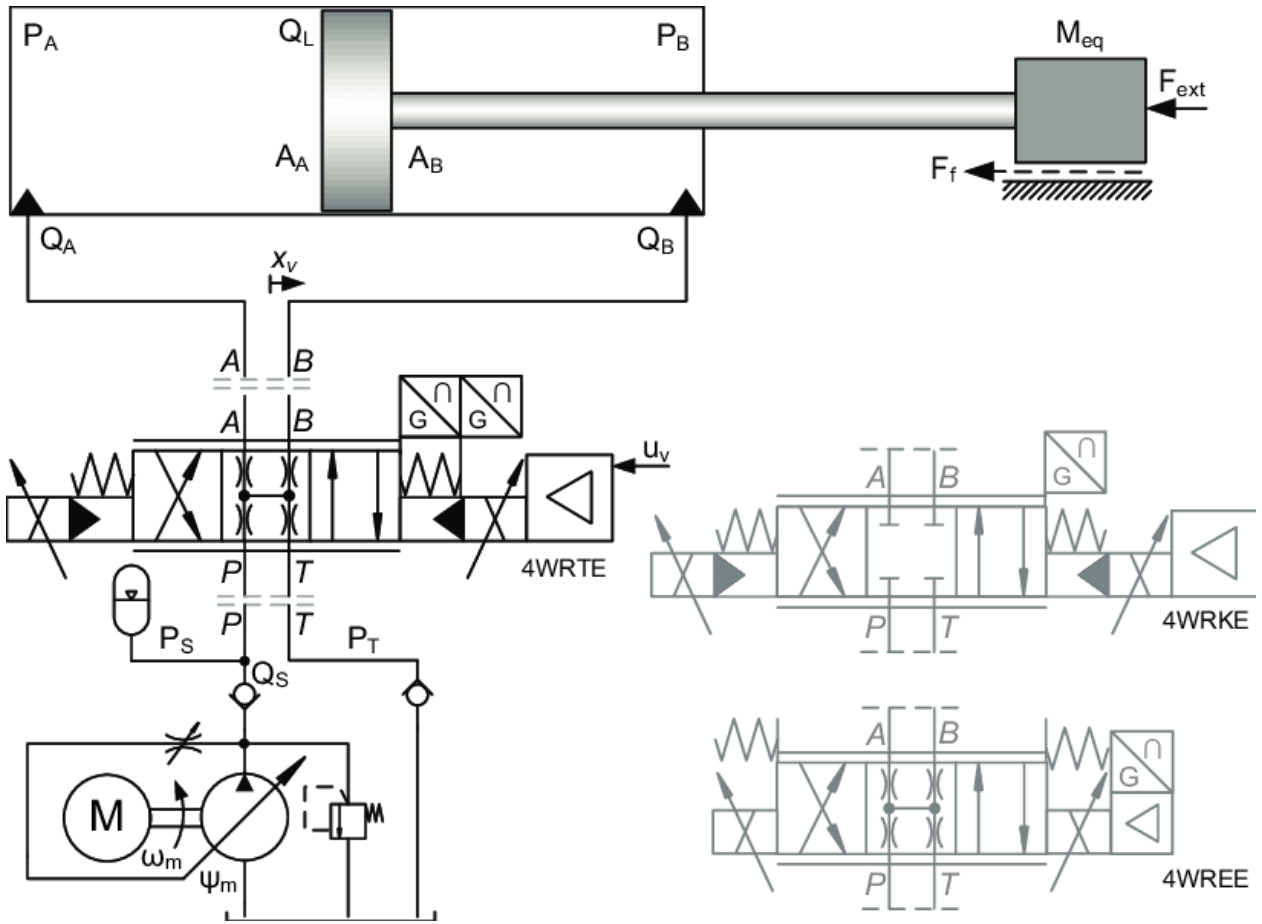


(c) Both valves open

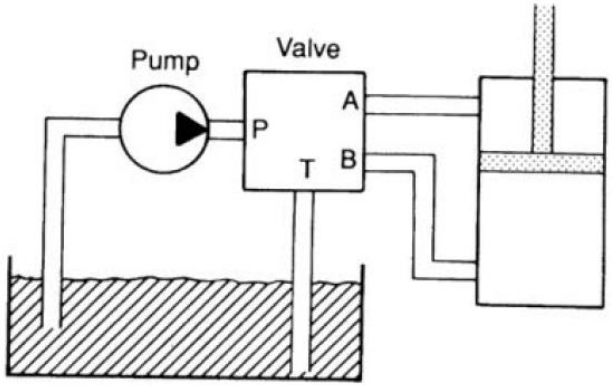


(d) Pressure readings

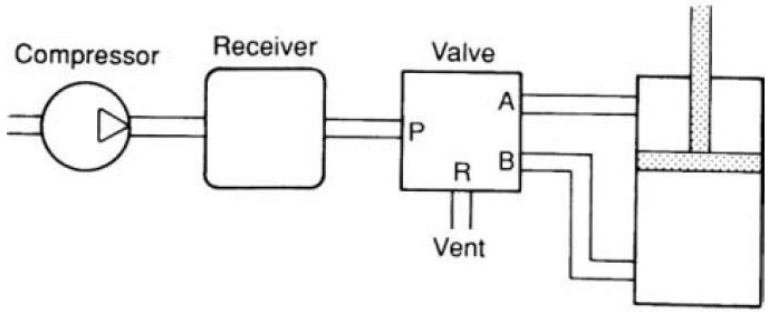
Schematics


P_A
Q_L
P_B
M_eq
F_ext
A_A
A_B
F_f
Q_A
Q_B
x_v
A
B
G
u_v
4WRTE
P
T
P_S
P_T
Q_S
M
ω_m
ψ_m
4WRKE
4WREE

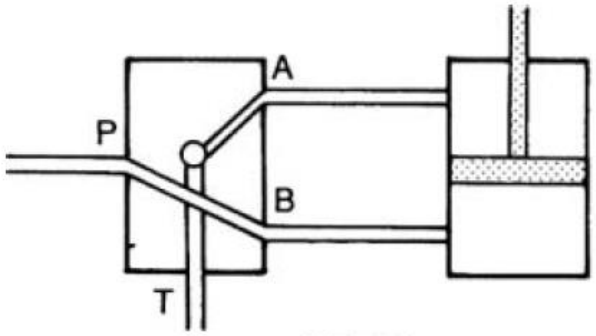
Valves



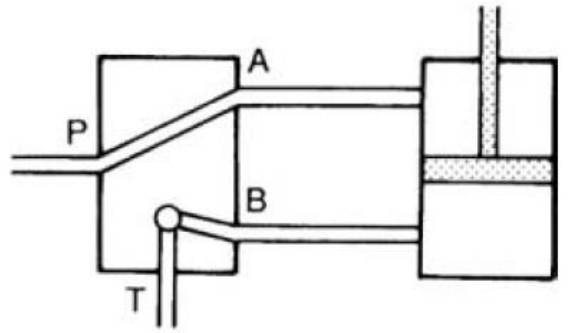
(a) Hydraulic system



(b) Pneumatic system

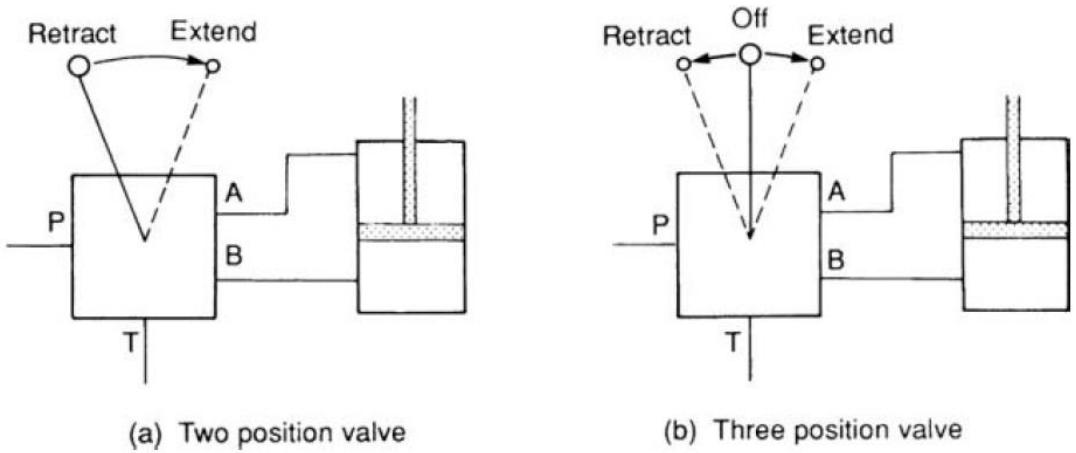


Extend



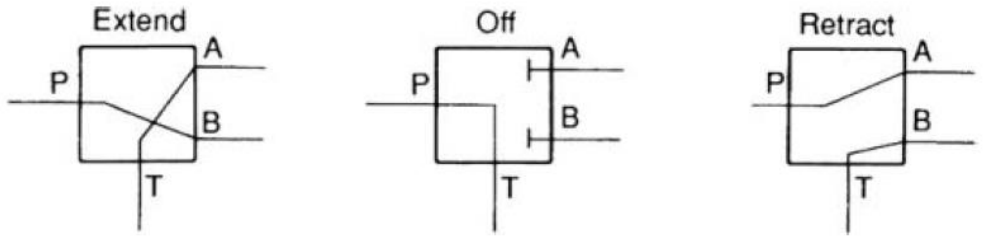
Retract

Operation modes



(a) Two position valve

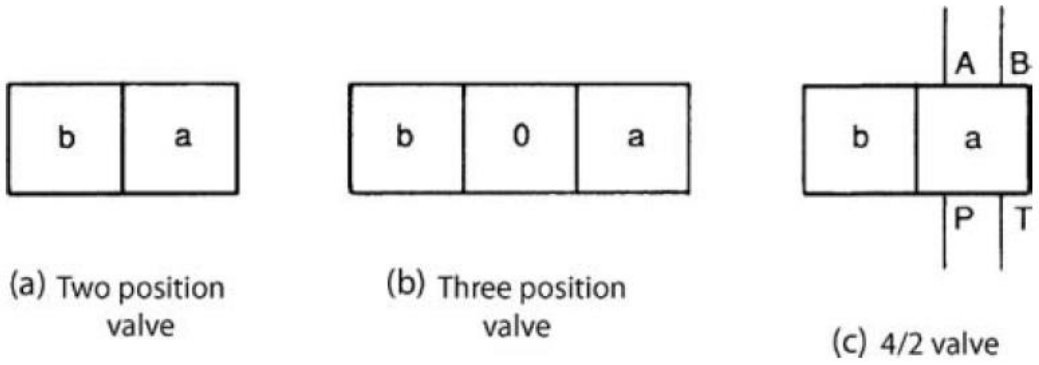
(b) Three position valve



Designations

Port	Designation
Working lines	A, B, C and so on
Pressure (power) supply	P
Exhaust/return	R, S, T and so on (T, for tank, is normally used for hydraulic systems, R and S for pneumatic systems)
Control (pilot) lines	Z, Y, X and so on

Basic graphic symbols

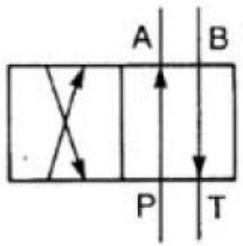


(a) Two position valve

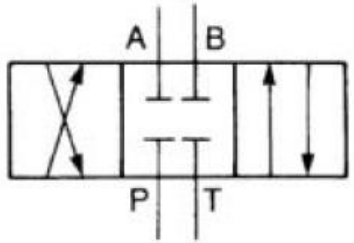
(b) Three position valve

(c) 4/2 valve

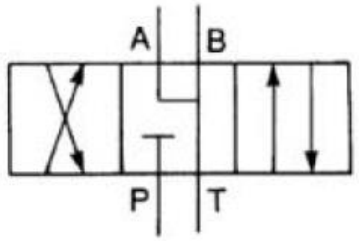
Types



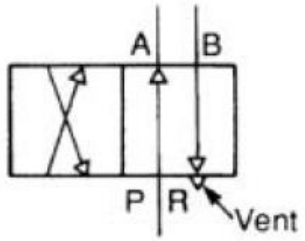
(a) 4/2 valve



(b) 4/3 valve center off (load isolated)

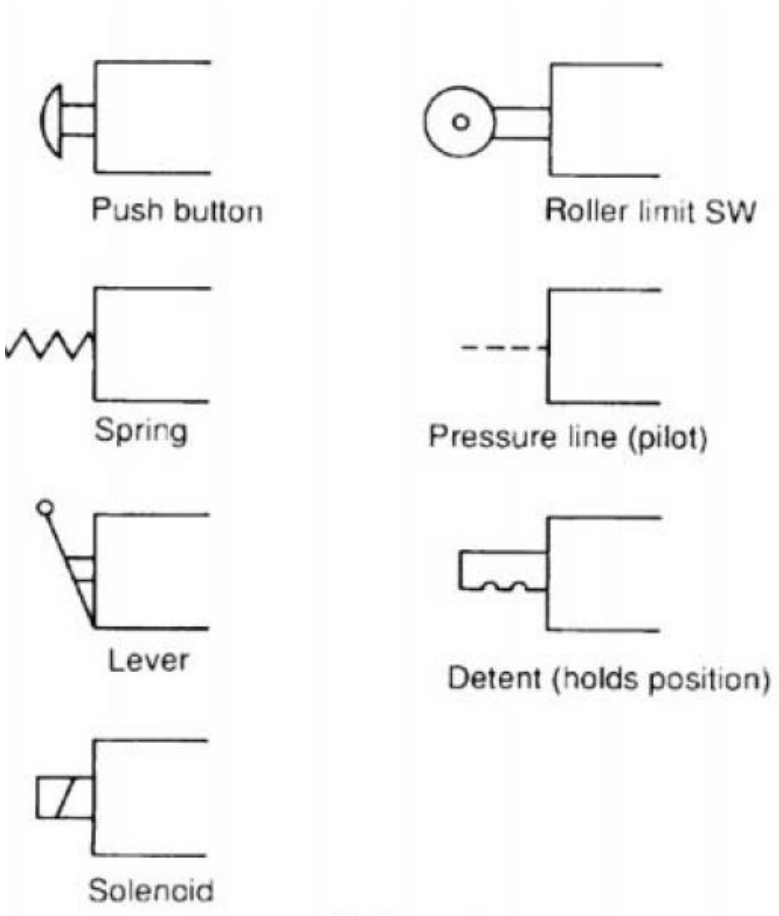


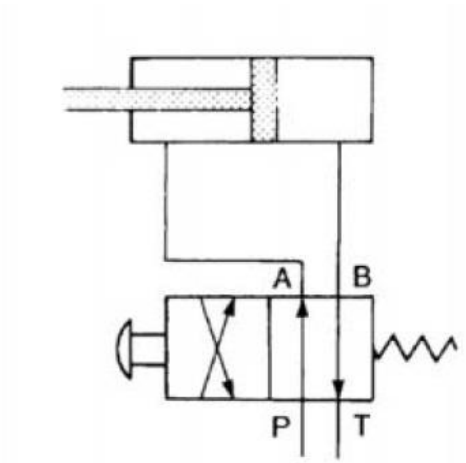
(c) 4/3 valve, load free in center



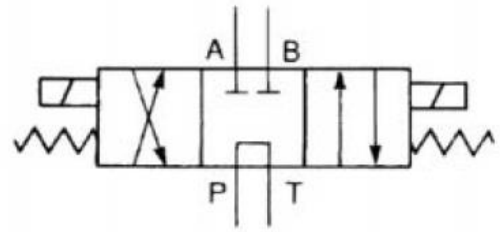
(d) Pneumatic valve with vent (pneumatic valve often presented with unshadded arrow heads)

Actuation symbols





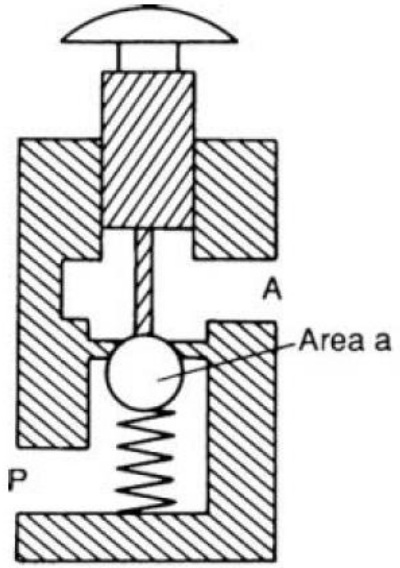
(b) Pushbutton extend, spring retract when pushbutton released



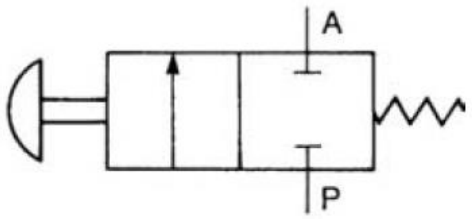
(c) 4/3 valve, solenoid operated, spring return to center. Pressure line unloads to tank and load locked in center position

Examples of valves (1)

- 2/2 poppet valve



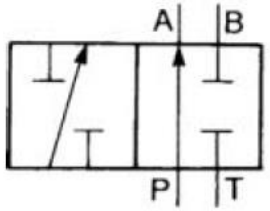
(a) Construction



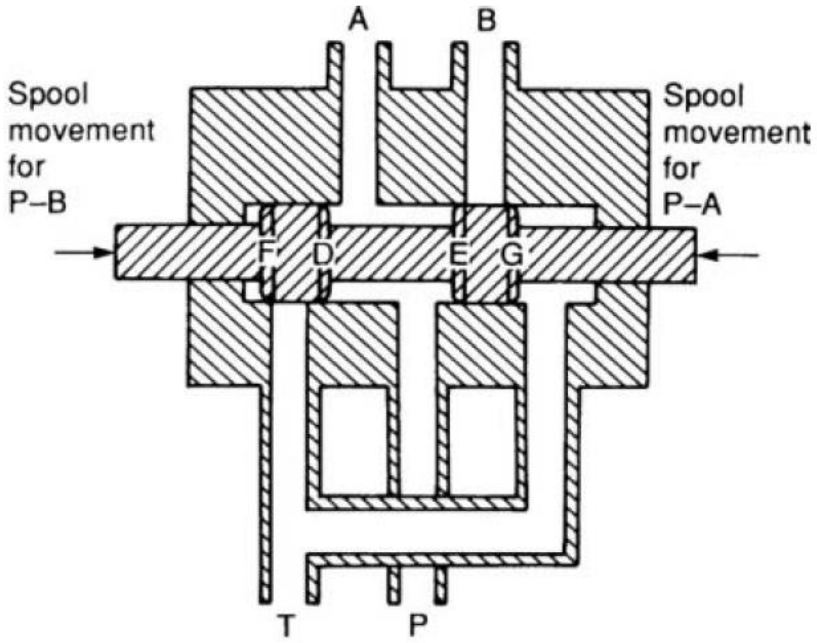
(b) Symbol

Examples of valves (2)

- Two-way spool valve



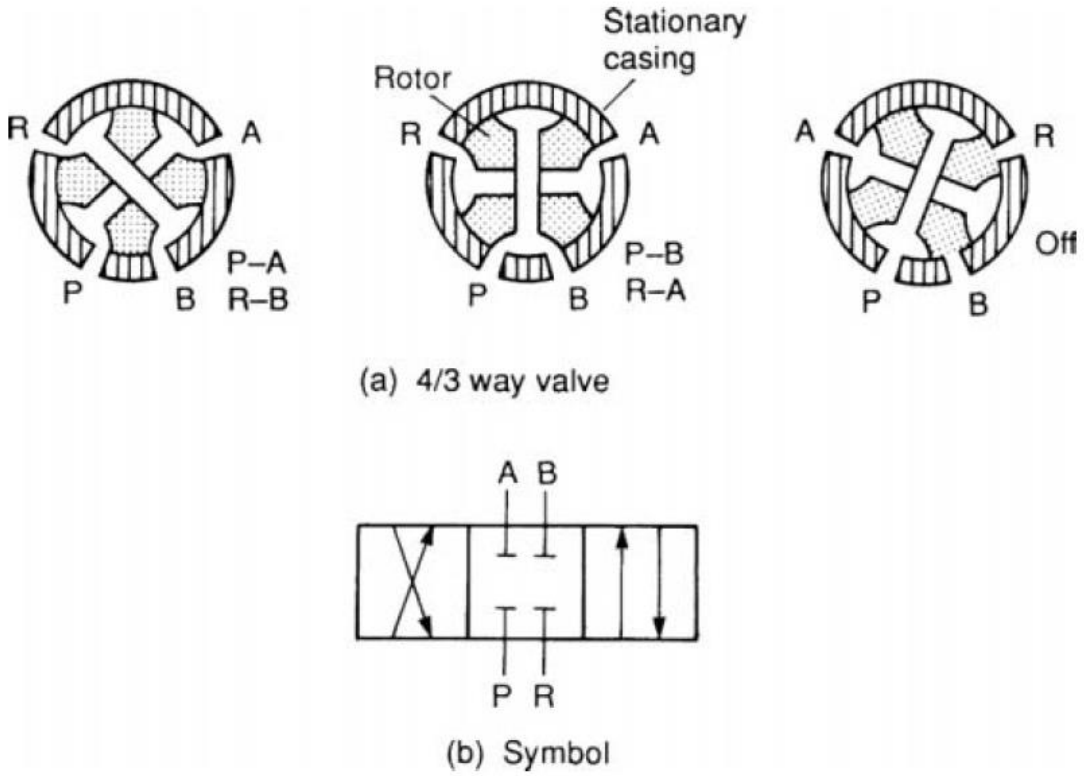
(a) Symbol



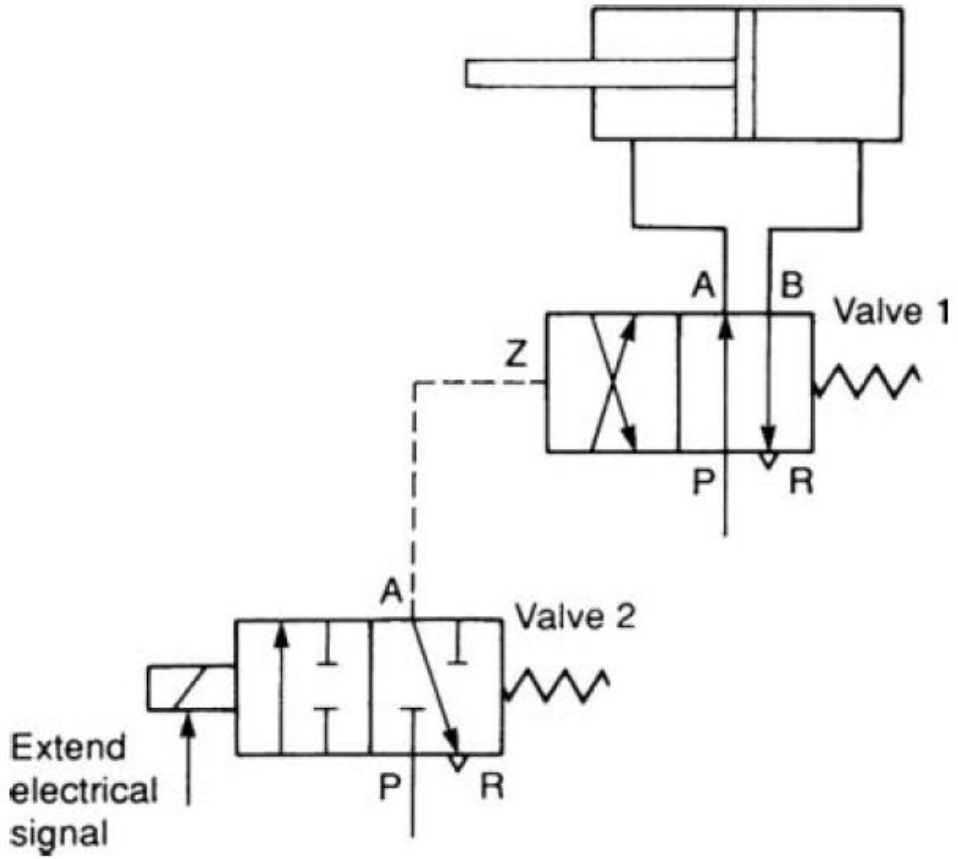
(b) Construction

Examples of valves (3)

- Rotary 4/3 valve



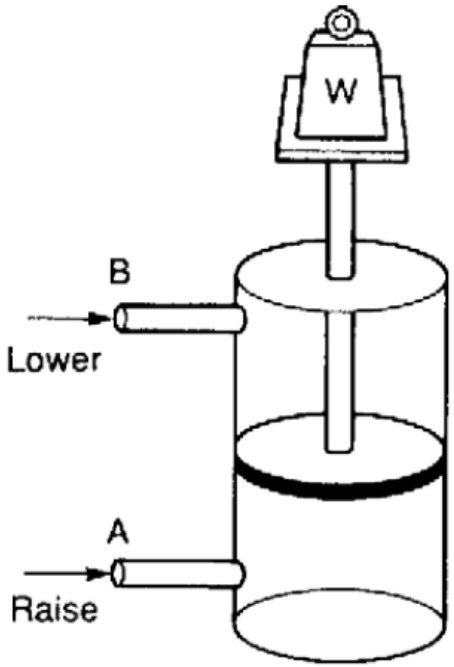
Pilot operated valve

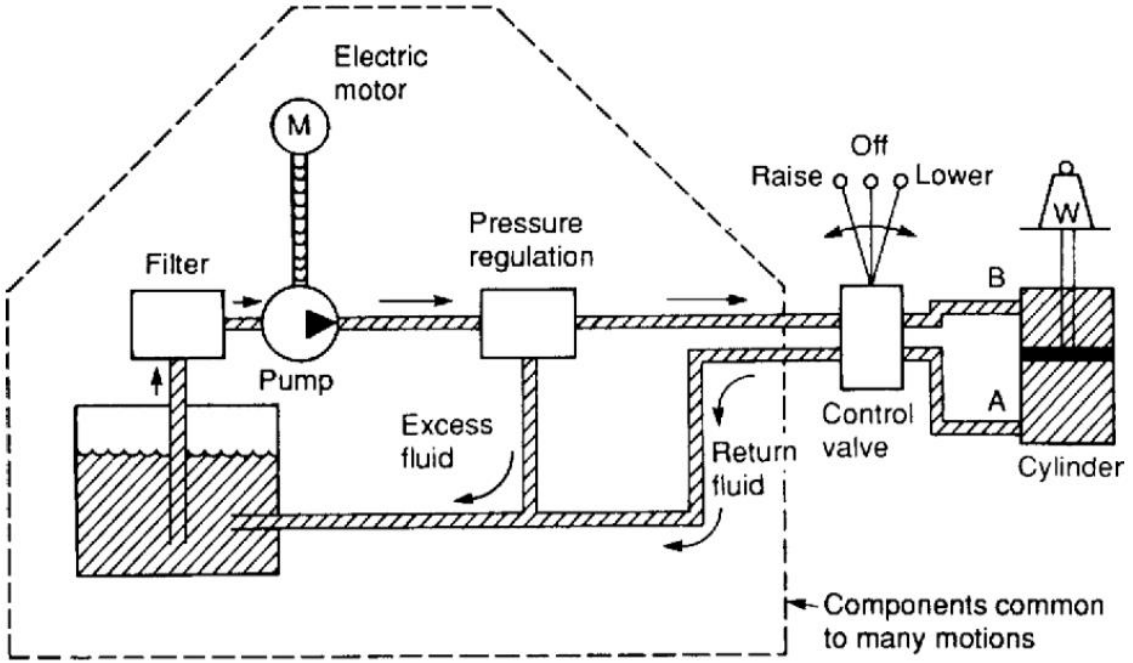


Modeling

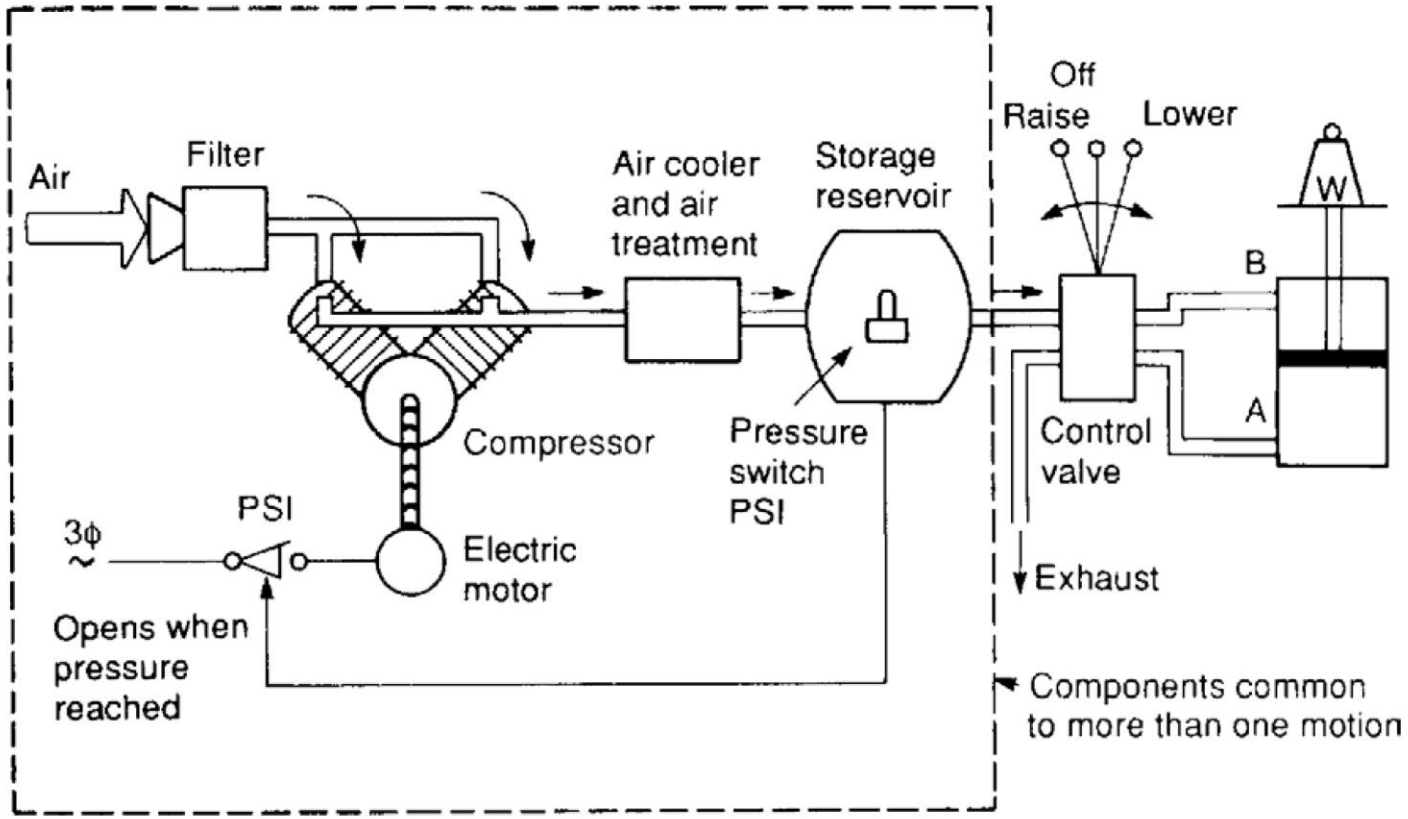
- Matlab/Simulink

A hydraulic solution

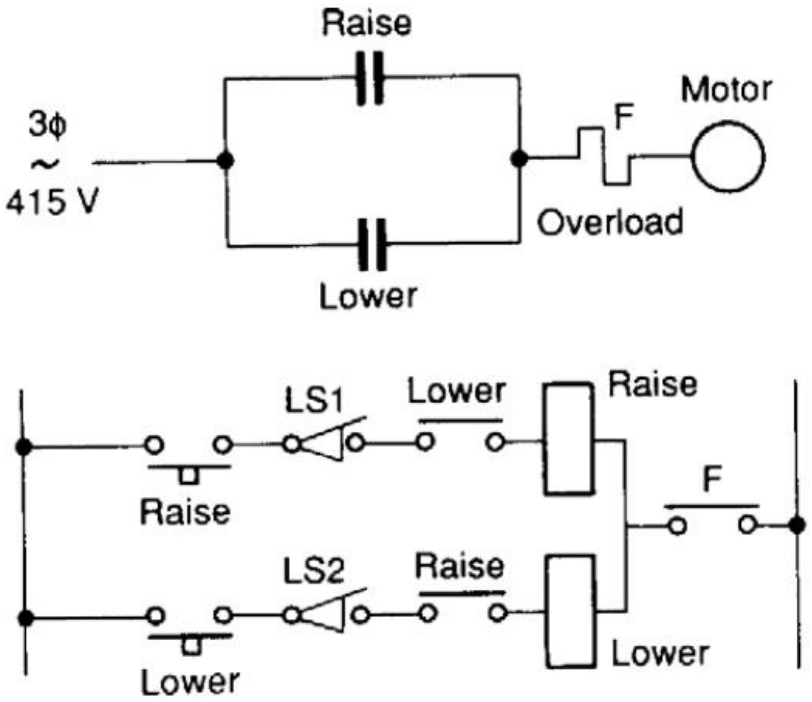


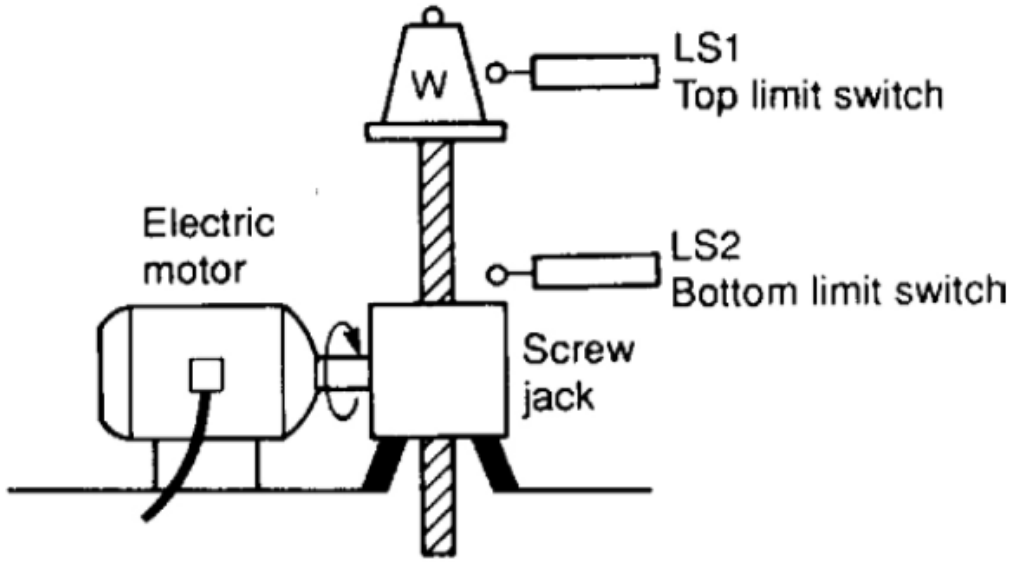


A pneumatic solution



An electric solution





Comparison of actuators

	Electrical	Hydraulic	Pneumatic
Energy source	Usually from outside supplier	Electric motor or diesel driven	Electric motor or diesel driven
Energy storage	Limited (batteries)	Limited (accumulator)	Good (reservoir)
Distribution system	Excellent, with minimal loss	Limited, basically a local facility	Good, can be treated as a plant wide service
Energy cost	Lowest	Medium	Highest
Rotary actuators	AC and DC motors. Good control on DC motors. AC motors are cheap	Low speed. Good control. Can be stalled	Wide speed range. Accurate speed control is difficult
Linear actuators	Short motion via solenoid. Otherwise via mechanical conversion	Cylinders. Very high force	Cylinders. Medium force
Controllable force	Possible with solenoid and DC motors. Complicated by need for cooling	Controllable high force	Controllable medium force
Points to note	Danger from electric shock	Leakage dangerous and unsightly. Fire hazard	Noise

Actuator operational ranges