MENG2520 Pneumatics and Hydraulics

Module 6 – Pneumatic Equipment

-Actuators and Control Devices

Pneumatic Equipment – Actuators and Control Devices

The actuators are the devices which are ‘doing the work’ and the control devices which direct the work

In this Module we will study

- **Cylinder and motors**
- **Flow Control Valves**
- **Directional Control Valves**

Pneumatic System

Air Compressor – reduces volume of atmospheric air and hence increases its pressure

Air Dryer – reduces moisture from air after compression

Air Tank – stores compressed air and acts an ‘infinite’ supply for the systems

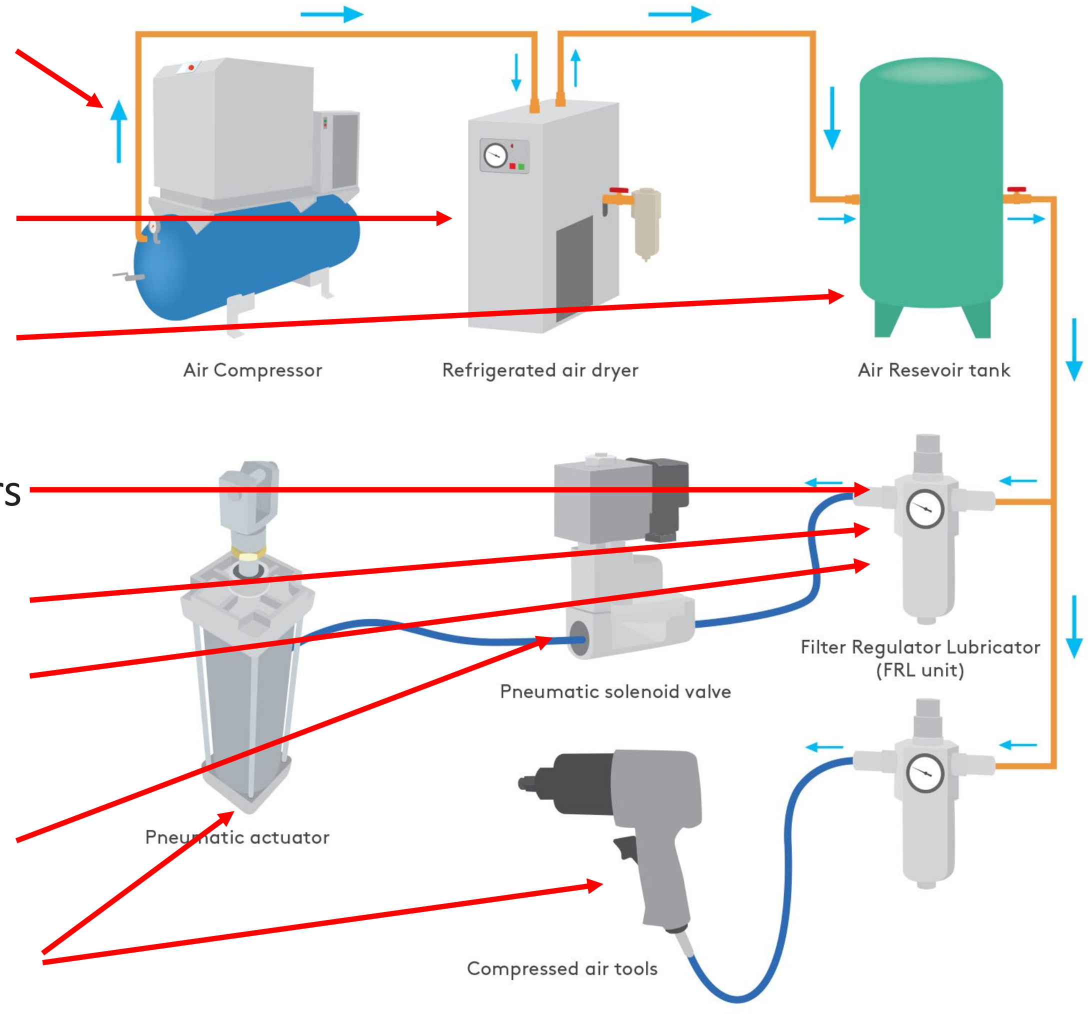
Filter – removes contaminants that can damage DCVs and actuators

Regulator – reduces the pressure to the actuator

Lubricator – adds a fine mist of oil for lubricating the DCV and actuator’s moving parts

Valve – controls the direction and movement of the air

Actuator – converts the pneumatic power into mechanical power



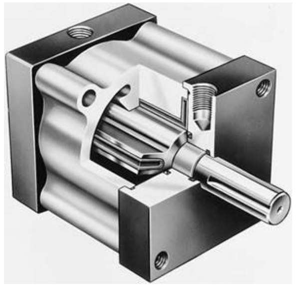
https://www.essentracomponents.com/en-gb/news/guides/hydraulics-versus-pneumatics

Actuators

The manufacturing industry uses two types of actuators:

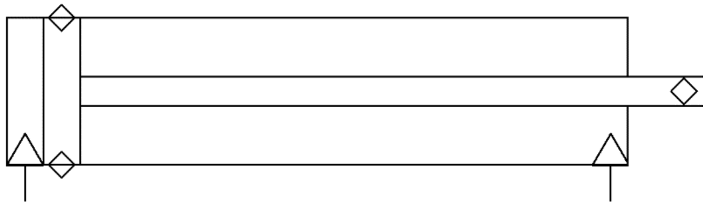
Linear Actuators — Move in a linear motion and are used to apply force to push or to pull.

Rotary Actuators - Move in a rotary motion and are used apply torque in either a clockwise or counter-clockwise direction.

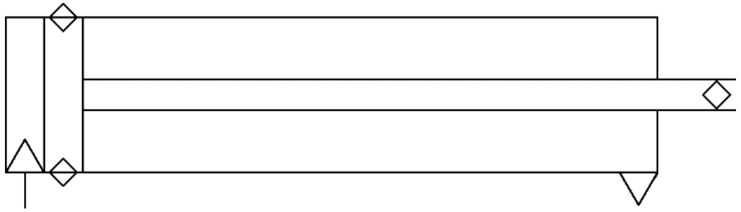


Linear Actuator (Cylinder) Symbols

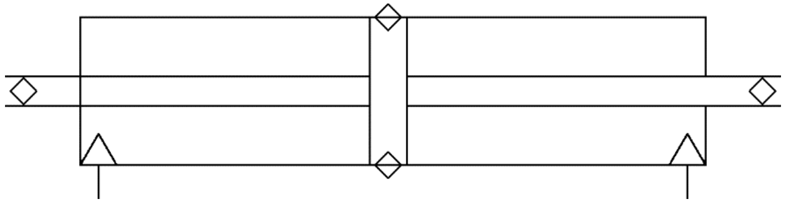
Double acting cylinder



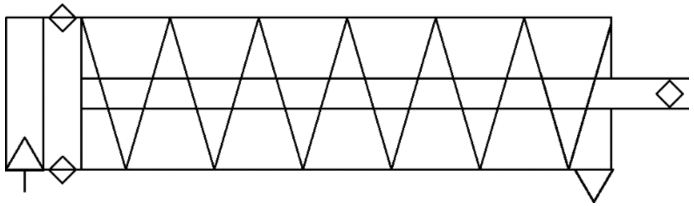
Single acting load return cylinder



Double Rod cylinder



Single acting load spring cylinder

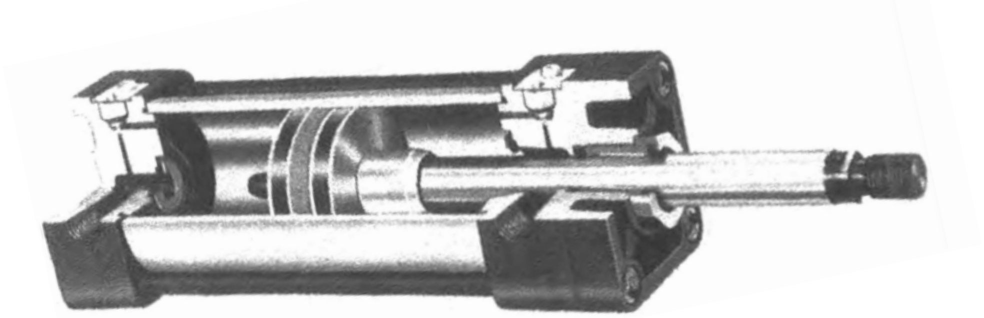


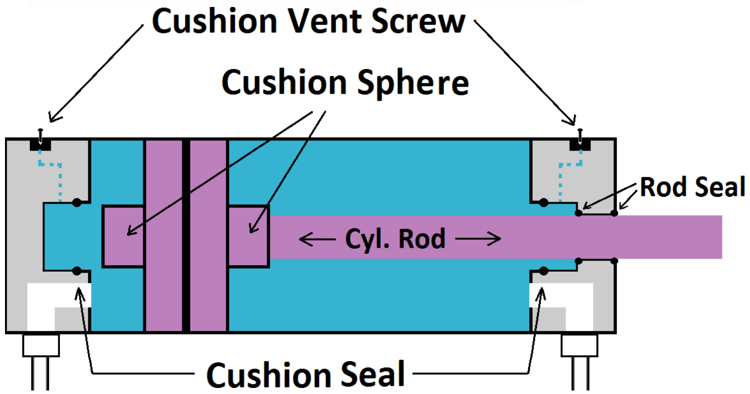
Cylinder Cushioning

Cushions are used to dampen the end motion of the cylinder. Much like shock absorbers. They are used when the cylinder is in Quick free motion. (Light or No Load applications)

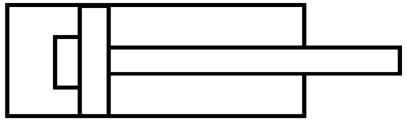
Such as returning the cylinder to its start position.

Benefits: Using cushions will increase the operation life of the cylinder.

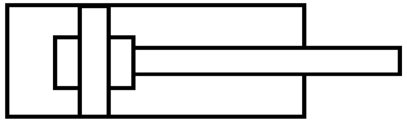




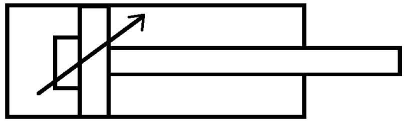
Trapped air is vented (Vent Screw) with an adjustable needle valve to set deceleration.



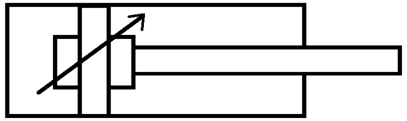
Single fixed Cushion Cylinder



Double fixed Cushion Cylinder



Single adjustable Cushion Cylinder



Double adjustable Cylinder

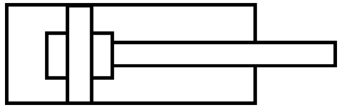
Cylinder Cushioning

A rejection cylinder on a conveyor in a parts manufacturer extends and retracts quickly to eject faulty parts off the conveyor.

The cylinder fully extends quickly and pushes the part off the conveyor and then retracts quickly. It reaches end of stroke abruptly in both extension and retraction.

What type of cushioning should be used?

Use double cushioning



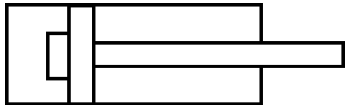
A clamping mechanism holds onto a paint can in an assembly line.

When an empty paint can arrives at a filling station, a cylinder extends and clamps onto the can keeping it in place. When the can is full of paint, the cylinder retracts quickly. During extension, the cylinder only gets to the clamping distance.

During retraction, the cylinder reaches the end of its stroke abruptly.

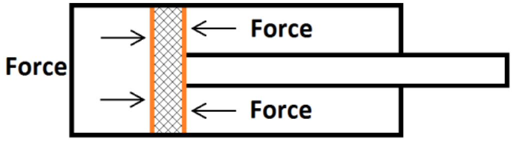
What type of cushioning should be used?

Use single cushioning



Linear Actuator Specifications

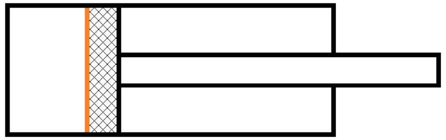
Cylinder Piston — Captures the force of the pressurized air.



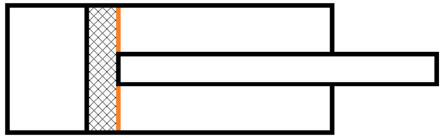
Cylinder Bore — Diameter of the piston.

Area — There are two piston areas. One creates the Extension force and the other creates the Retraction force.

Extension Area A_E

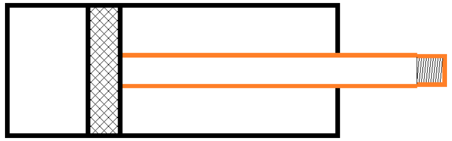


Retraction Area A_R (Does not include Rod Area)



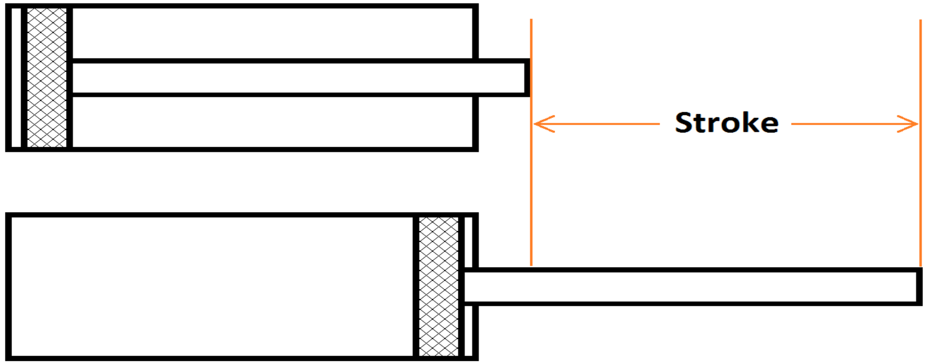
Linear Actuator Specifications

Cylinder Rod — The rod end is threaded for the Rod End Mount.



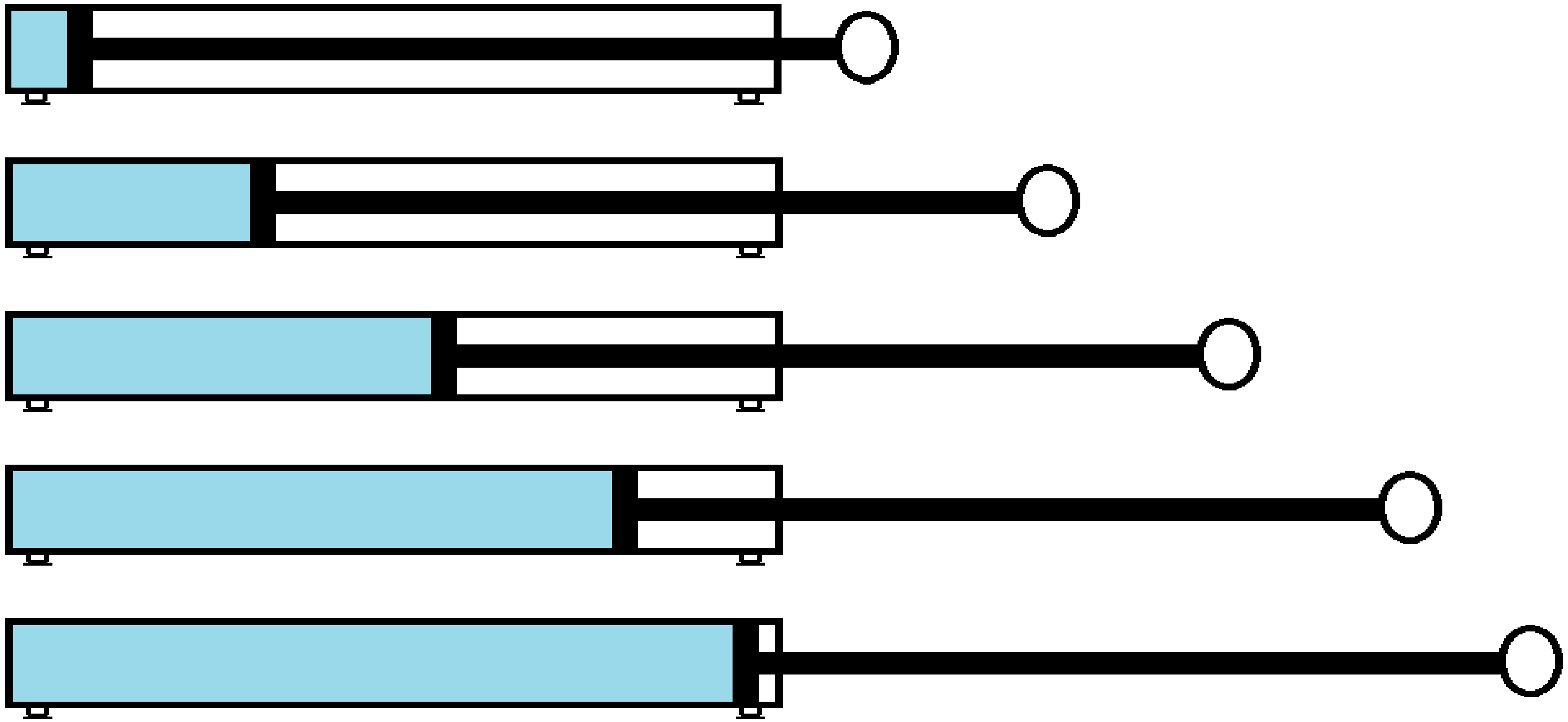
Rod Diameter — Important when calculating AR.

Stroke — Distance that the Rod moves from fully retracted to fully extended. This is not the Clamping Distance.



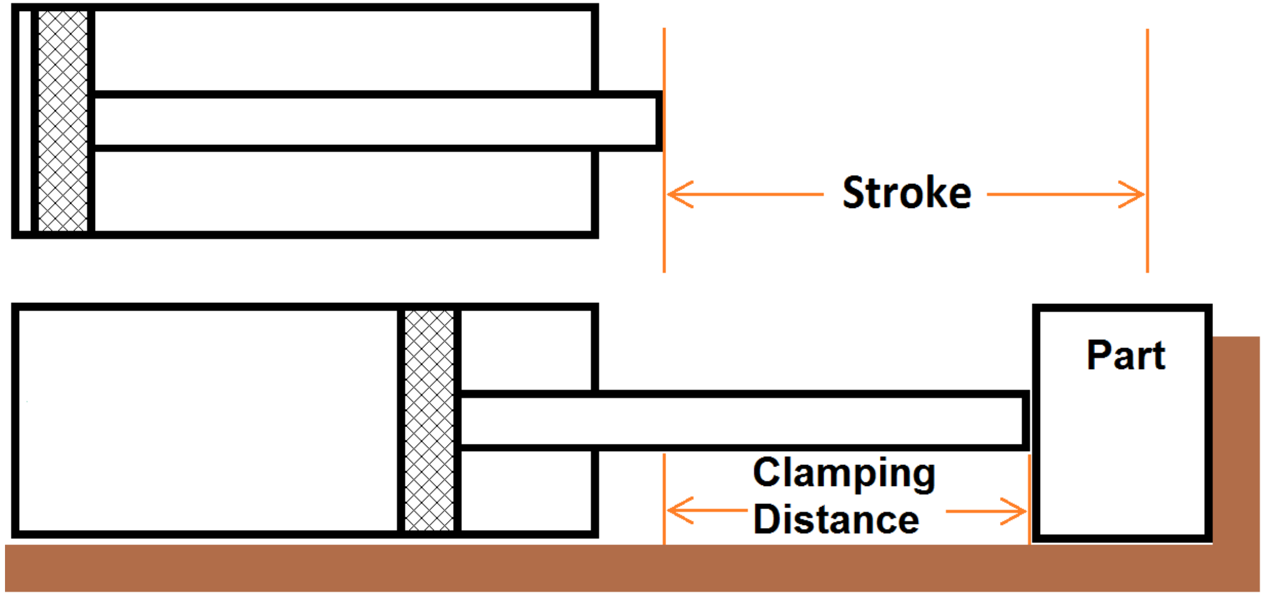
Rod Travel Distance

Rod Travel — This is the distance that the rod moves during its operation. The Rod Travel length is not always equal to the stroke.



Rod Travel (Clamping Distance)

Clamping Distance -Always less than the Stroke. The Clamping Distance is the amount of Rod Travel during a cylinders clamping operation. It is from full retraction to a little less than full extension.



Application

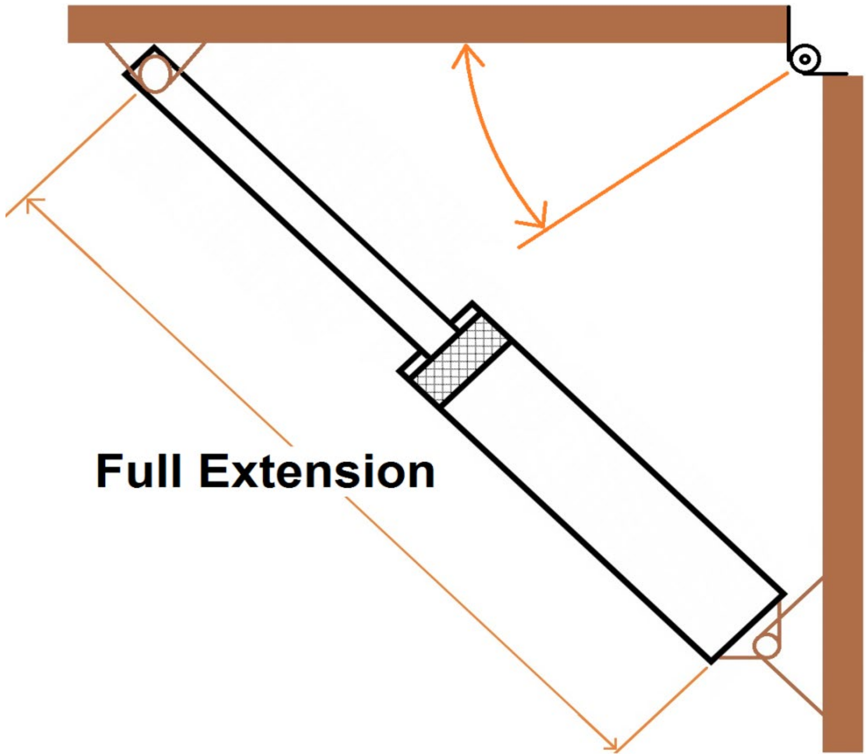
To ensure the part is fully clamped and fixed firmly by the cylinder, the clamping distance should be less that the stroke. This will allow for a high clamping force.

Therefore: Always be sure to select a cylinder with a stroke just a little longer than the required clamping distance.

Rod Travel (Full Extension Distance)

Full Extension Distance

This length is equal to the stroke. The Full Extension Distance is the amount of Rod Travel during the cylinder's operation. It is from full retraction to full extension.



Application

A tabletop must lower and rise to a vertical position and stop.

Therefore: The cylinder will fully extend and retract. Clamping force is not required in this case. The cylinder will stop at full extension and the table top will stay fixed in a horizontal position.

Cylinder Force

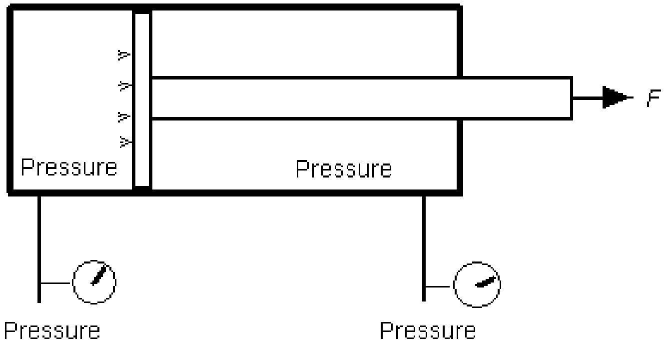
A linear actuator creates two different forces.

Extension force F_E

Retraction force F_R

They are different due to the two different areas of the piston……

Extension Area A_E and Retraction Area A_R.



$$F = p \times A$$

$$F_E(lbs) = p(psi) \times \frac{\pi}{4}(d_{bore})^2$$

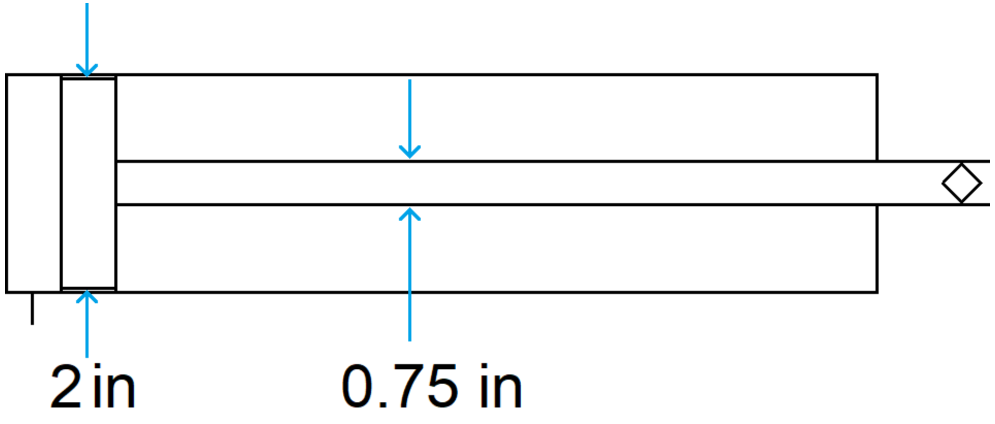
$$F_R(lbs) = p(psi) \times \frac{\pi}{4}\left(d_{bore}^2 - d_{rod}^2\right)$$

$$Force(lbs) = pressure\left(\frac{lbs}{in^2}\right) \times Area(in^2)$$

$$Force(N) = pressure(Pascals) \times Area(m^2)$$

Cylinder Force Example

A double acting cylinder extends and retracts with a pressure sources of 80 psi.
Calculate the extension and retraction forces.

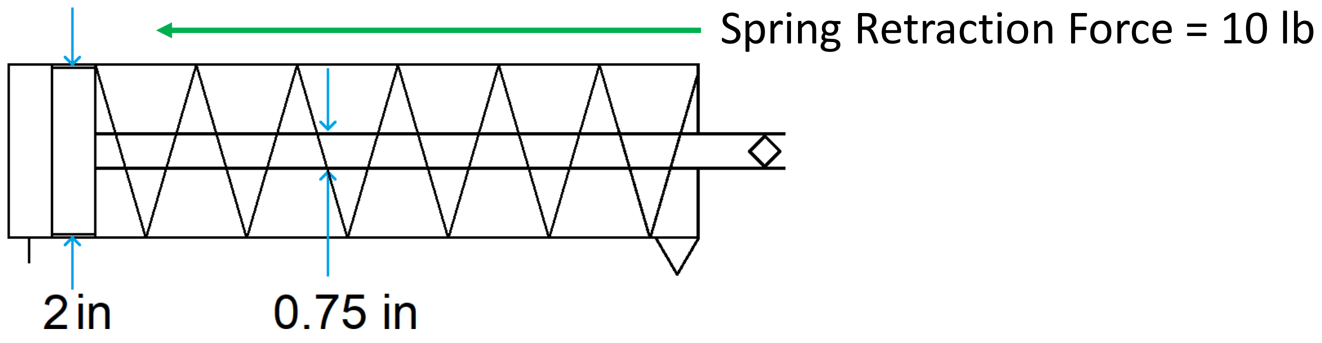


$$F_E(lbs) \;= p(psi) \times \frac{\pi}{4}(d_{bore})^2$$
$$F_E(lbs) \;= 80\ psi \times \frac{\pi}{4}(2in)^2$$
$$F_E(lbs) \;= 251\ lbs$$

$$F_R(lbs) \;= p(psi) \times \frac{\pi}{4}\left(d_{bore}^2 - d_{rod}^2\right)$$
$$F_R(lbs) \;= 80\text{psi} \times \frac{\pi}{4}(2in^2 - 0.75in^2)$$
$$F_R(lbs) \;= 216\ lbs$$

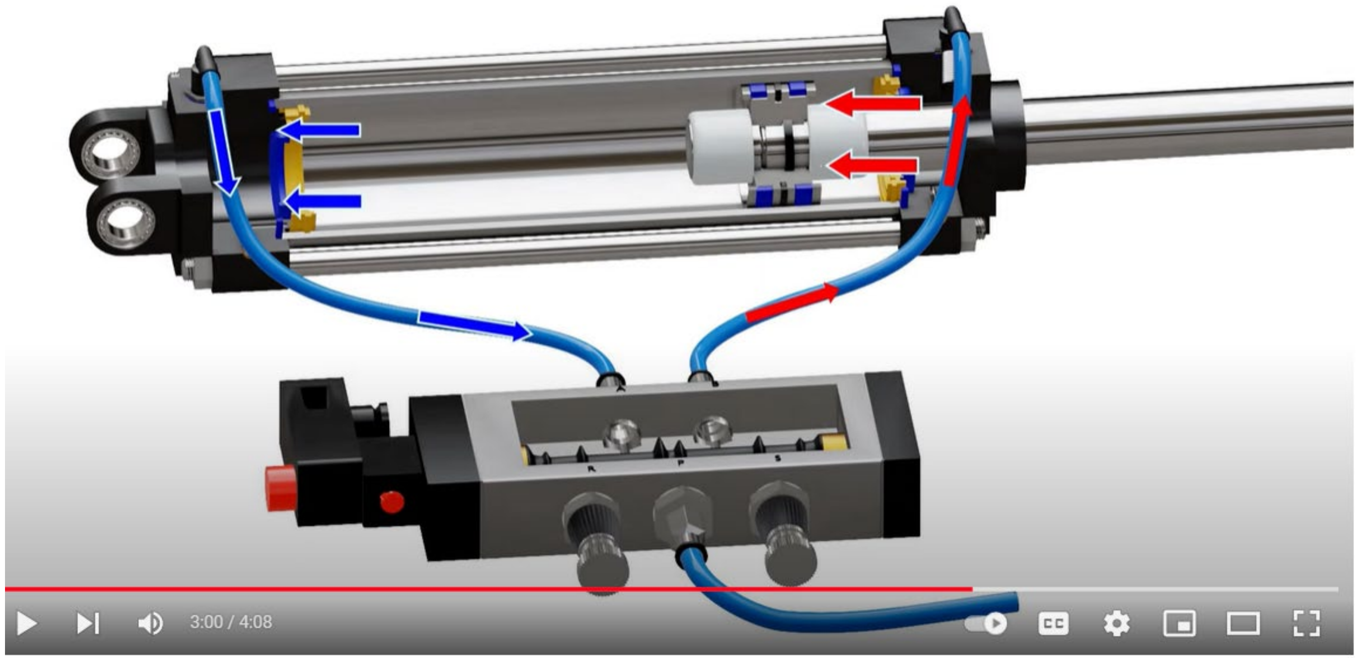
Cylinder Force Example

A spring return single acting cylinder extends with 80 psi. Calculate the extension force if the spring retraction force is 10 lbs?



$$F_E(lbs) = p(psi) \times \frac{\pi}{4}(d_{bore})^2 - F_{spring}$$
$$F_E(lbs) = 80\ psi \times \frac{\pi}{4}(2in)^2 - 10lbs$$
$$F_E(lbs) = 241\ lbs$$

Cylinder Operation Video



https://www.youtube.com/watch?v=hmz1h5fk2bI

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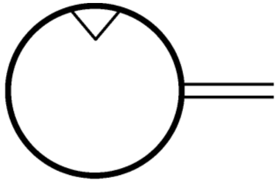
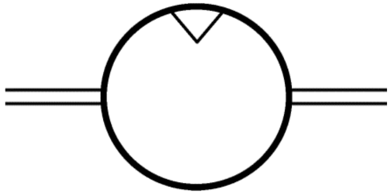
Rotary Actuators (Motor) Symbols

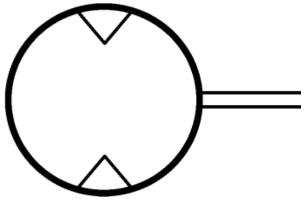
Air Motors



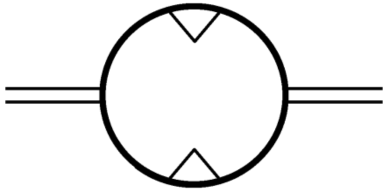
One Direction Rotation
Single Shaft



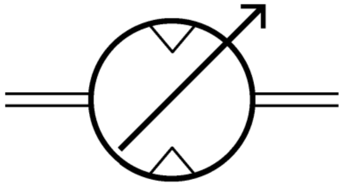
One Direction Rotation
Double Shaft



Bi-Direction Rotation
Single Shaft



Bi-Direction Rotation
Double Shaft



Variable Displacement
Bi-Direction Rotation
Double Shaft

Other Type of Motors

Rotary / Oscillator

These either go:
Back & Forth
or
Vibrate (Oscillate)

Rotary Actuators

Air Motors provide a smooth source of rotational torque and power

They are not susceptible to overload damage and can be stalled for long periods without any heat concerns

They can be started and stopped very quickly and with pressure regulation and metering of flow can provide infinitely variable torque and speed.

Applications:

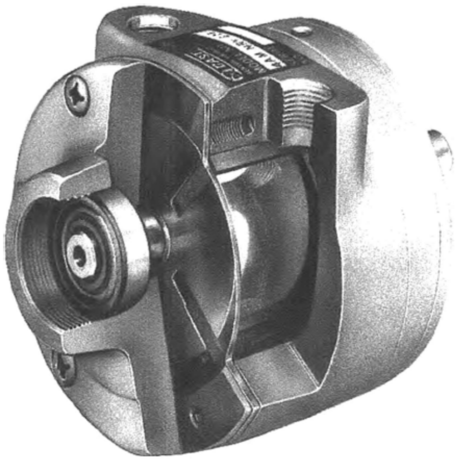
Drills

Grinders

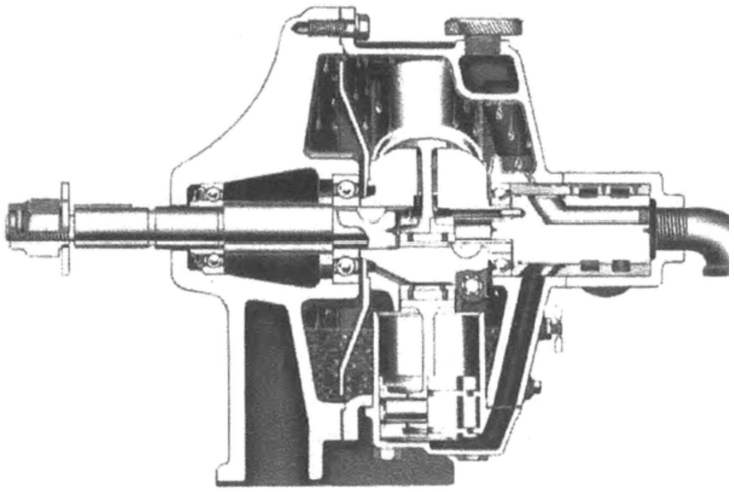
Impact wrenches

Hoists

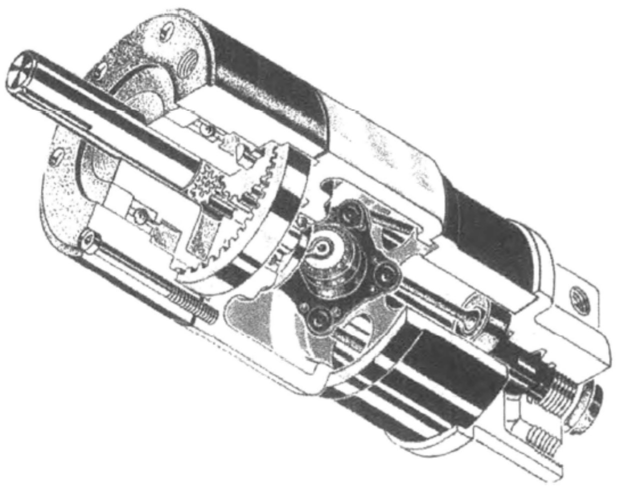
sunextools.com



Vane Motor



Radial Piston Motor



Axial Piston Motor

Rotary Actuators

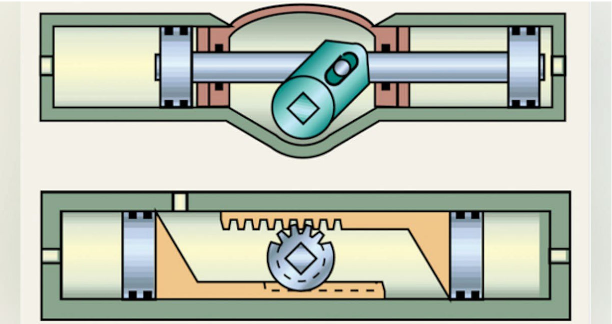
Limited Rotation Actuator

The linear motion of the pistons is converted into rotary motion by a rack and pinion mechanism

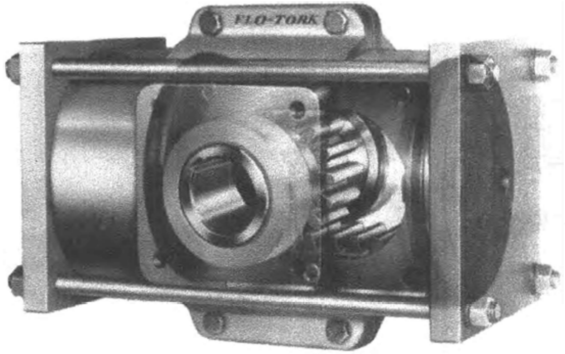
Applications

Open and close devices such as access doors

Actuate valves



https://www.powermotiontech.com/fluid-power-basics/motors-actuators/article/21882753/engineering-essentials-rotary-actuators



Rotary Actuators

Index Table

The linear motion of the piston indexes a table by a preset rotation angle

Applications

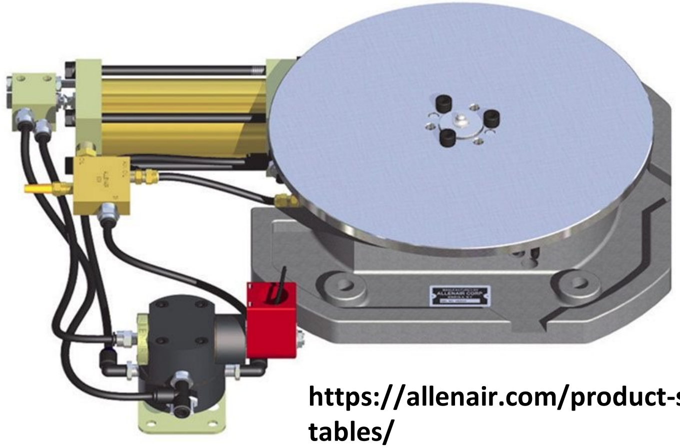
Moving containers under a nozzle and holding for liquid fill

Moving an engine component around to a drill stand

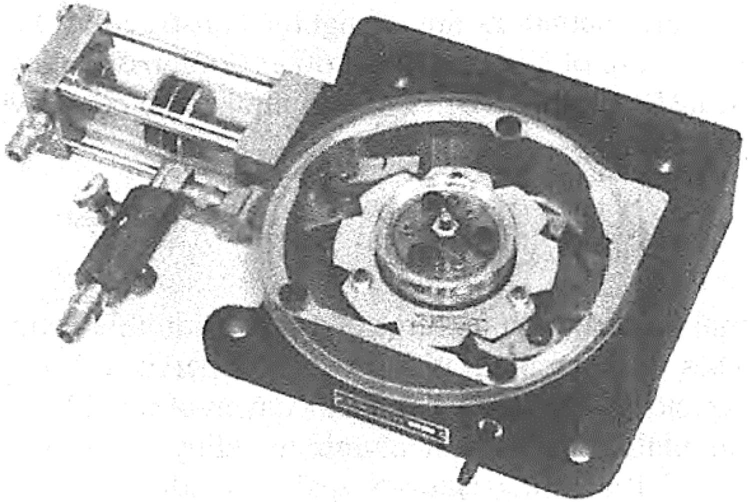
Moving a casting into position to have a static bearing pressed into place

Moving a part around to have a cast face milled flat

Moving this machined part next to a visual inspection sensor



https://allenair.com/product-solutions/rotary-tables/



Rotary Actuator Air Requirements

Pneumatic actuators are used to drive a variety of power

Air requirements are in terms of flow rate and pressure

PNEUMATIC TOOL	scfm	STANDARD m^3/min
HOISTS	5	0.14
PAINT SPRAYERS	10	0.28
IMPACT WRENCHES	10	0.28
HAMMERS	20	0.57
GRINDERS	30	0.85
SANDERS	40	1.13
ROTARY DRILLS	60	1.70
PISTON DRILLS	80	2.36

sunextools.com

https://www.sambedbod.com

airflow requirements in scfm for a number of average-size pneumatic tools at 100 psig (687 kPa gage)

Rotary Actuator Air Requirements Example

A single-acting pneumatic cylinder with a 1.75-in piston diameter and 6-in stroke drives an indexing table using 100-psig air at 80°F. If the cylinder reciprocates at 30 cycles/min, determine the air-consumption rate in scfm (cfm of air at standard atmospheric conditions of 14.7 psia and 68°F).

Solution The volume per minute (Q_2) of 100-psig, 80°F air consumed by the cylinder is found first.

$$Q_2(\text{ft}^3/\text{min}) = \text{displacement volume (ft)}^3 \times \text{reciprocation rate (cycles/min)}$$

$$= \text{piston area (ft)}^2 \times \text{piston stroke (ft)} \times \text{recip. rate (cycles/min)}$$

$$= \frac{\pi}{4}\left(\frac{1.75}{12}\right)^2 \times \frac{6}{12} \times 30 = 0.251 \text{ ft}^3/\text{min}$$

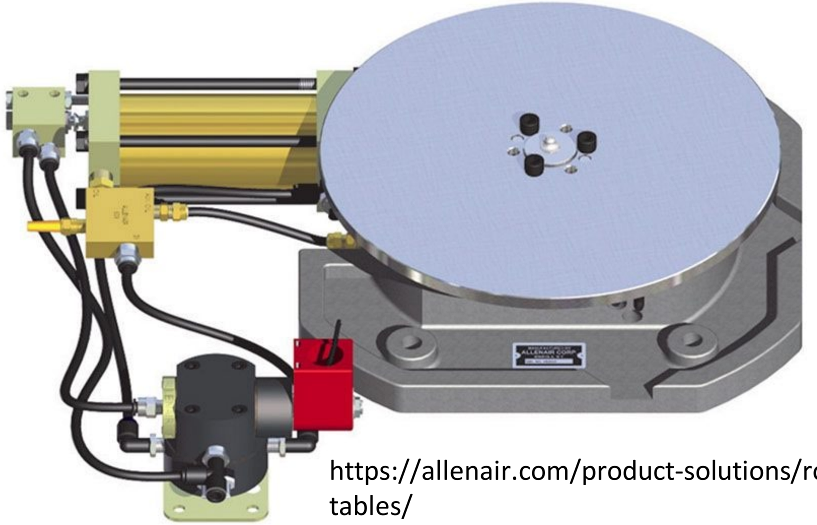
To obtain the volume per minute (Q_1) of air (scfm) consumed by the cylinder, we use Eq. (13-7):

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right)$$

where $p_2 = 100 + 14.7 = 114.7$ psia,
$p_1 = p_{\text{atm}} = 14.7$ psia,
$T_2 = 80 + 460 = 540°\text{R}$,
$T_1 = 68 + 460 = 528°\text{R}$.

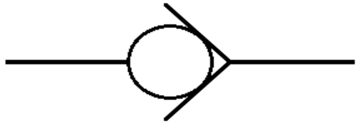
Substituting values yields

$$Q_1 = 0.251\left(\frac{114.7}{14.7}\right)\left(\frac{528}{540}\right) = 1.91 \text{ scfm}$$

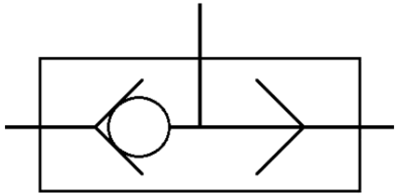


https://allenair.com/product-solutions/rotary-tables/

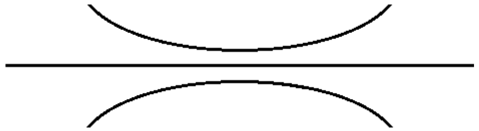
Flow Control



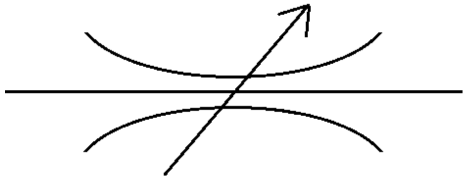
Check Valve



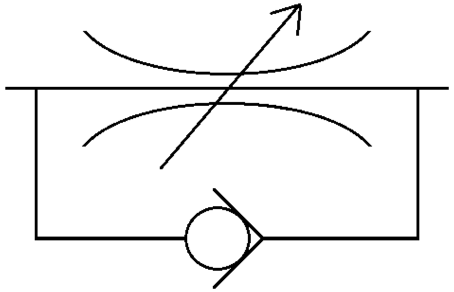
Shuttle Valve



Throttle Valve



Variable Throttle Valve



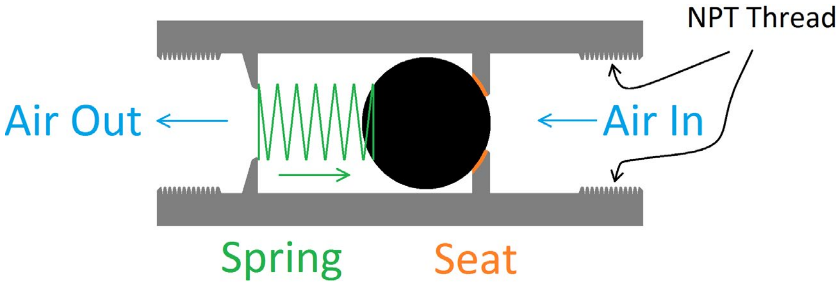
Non-Return Throttle Valve, Variable

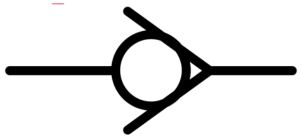
The Check Valve

Much like an electrical Diode, a Check Valve will only allow flow in one direction.

Inside the valve is a ball bearing that is pushed against a bearing seat by a spring.

Air flowing towards the bearing will either push it harder against the seat, sealing the valve, or push it away from the seat, opening the valve.





Cracking pressure varies depending on the size of the valve. The cracking pressure is the minimum upstream pressure that will operate the valve. Typically around 3-5 psi

Applications:

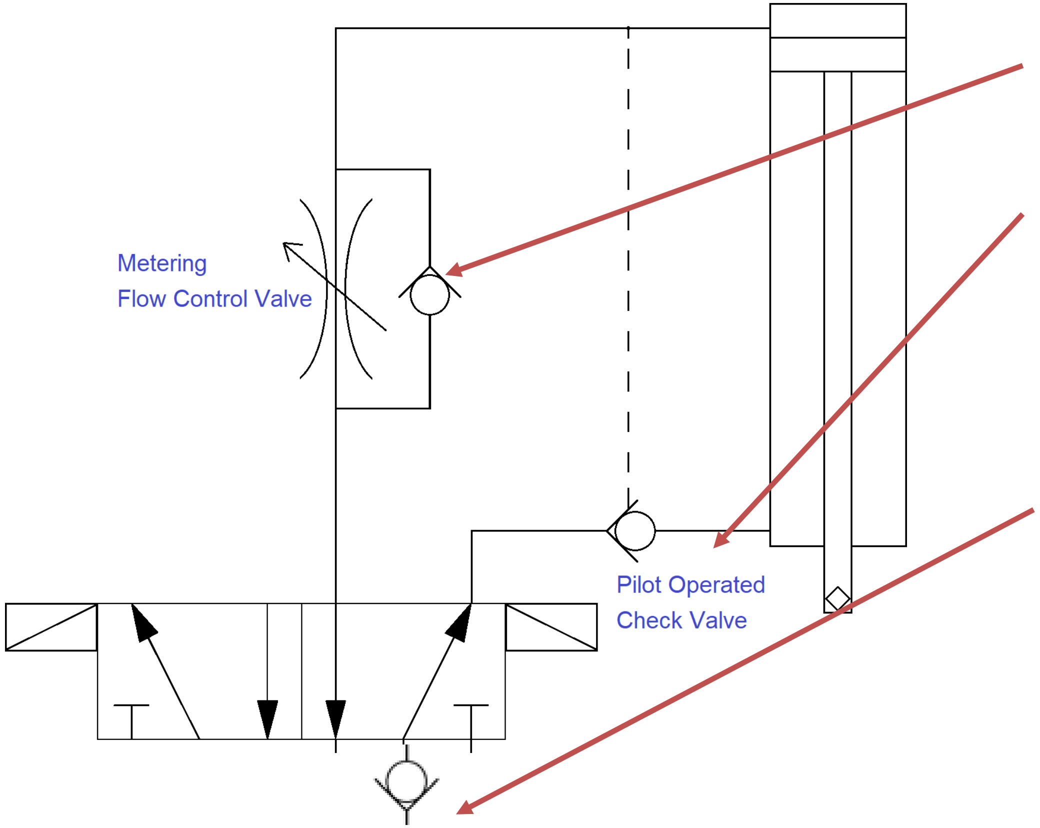
Prevent pressurized air from returning to a compressor

Ensure a rotary actuator can only rotate in one direction

Safety Applications:

Used to prevent Hose Whip. (Safety Check Valve).

Check Valve Applications



Check valve allow air to pass by FCV when retracting

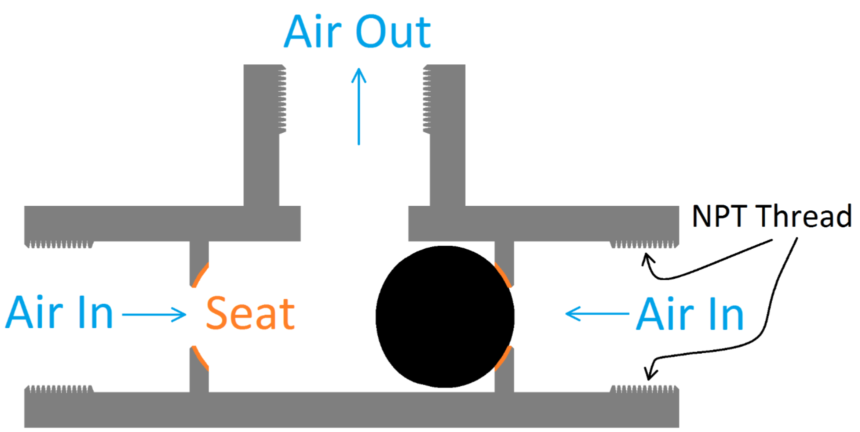
Pilot operated check valve ensures cylinder holds against gravity

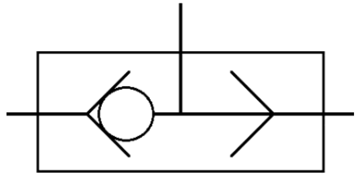
Check valve prevents pressurized air from load to entering rest of pneumatic system

Flow Control (Shuttle Valve)

Shuttle Valve allows two different pressure sources to be added to one pneumatic system. The Logic operation for this valve is an OR.

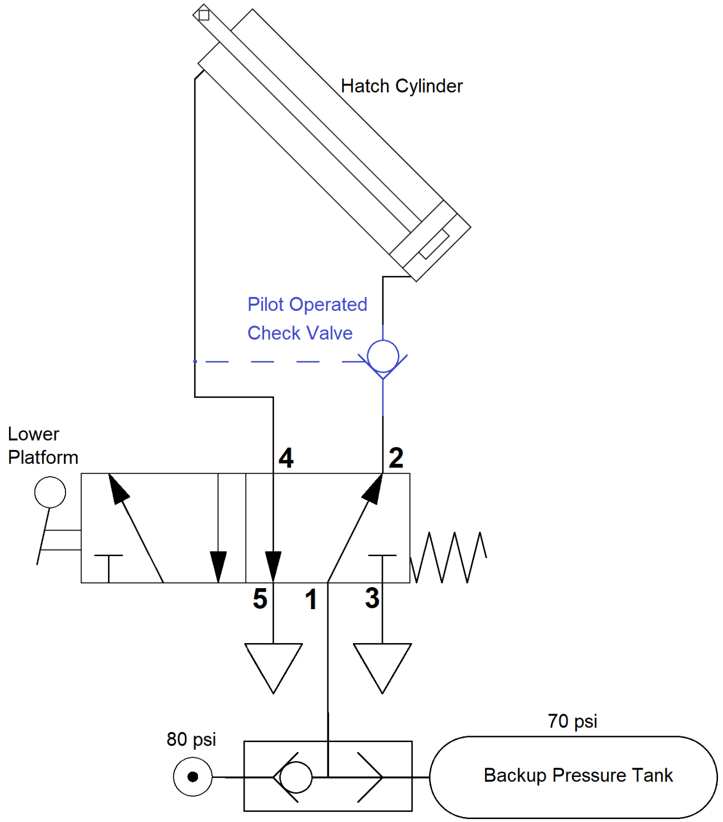
Higher Pressure Wins: Whichever input pressure is higher will vent out of the valve.





Application

Backup reserve power



Metering (Meter In and Meter Out)

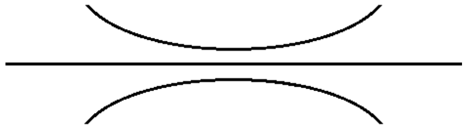
This is the process of controlling the flow in and out of an actuator. Metering controls the speed of movement of the actuator.

Flow in and out of the actuator is controlled by a Throttle Valve which restricts flow in or out of the actuator.

Meter In:

The process of restricting the flow INTO an actuator.

Not usually used for Pneumatic Systems



Throttle Valve
Schematic Symbol

Meter Out:

The process of restricting the flow OUT of the actuator

Mainly used in Pneumatic and Hydraulic Systems.

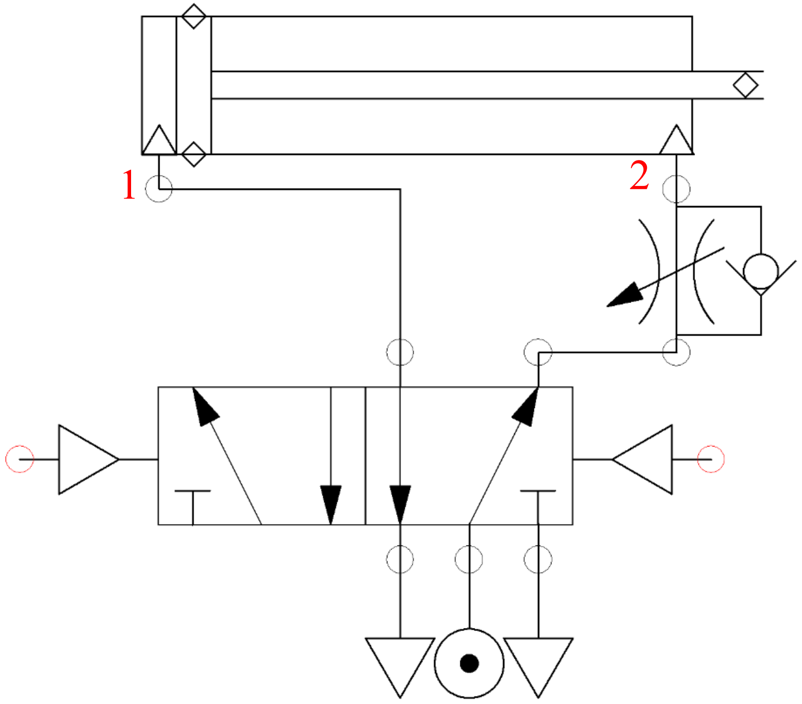
It is better to use Meter Out in pneumatic actuators because air is compressible and does not act as rigidly as hydraulic fluid. Meter Out creates more accurate control than restricting flow in.

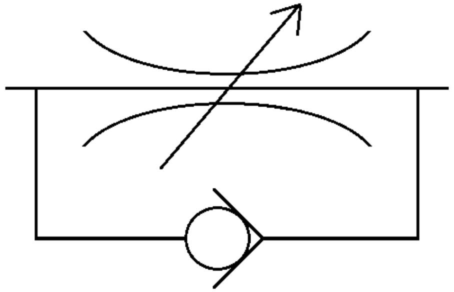
Metering (Meter Out)

Application of a Throttle Valve for Metering:

A Throttle Valve can restrict the flow out of an actuator if it is connected to the out port of the actuator (Port 2). This will slow the Extension motion.

A Check Valve in parallel with the Throttle Valve allows air to flow into Port 2 for unobstructed Retraction flow.





Non-Return Throttle Valve

Schematic Symbol

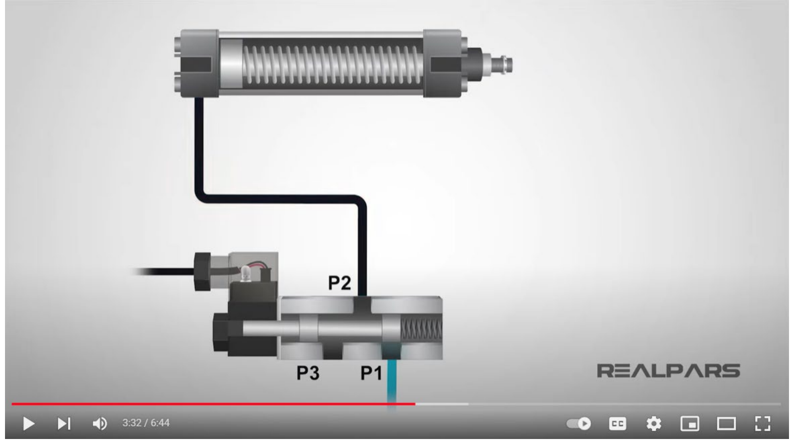
Control Valves

Their function is to direct the flow of air into the correct pipelines.

These valves can function:

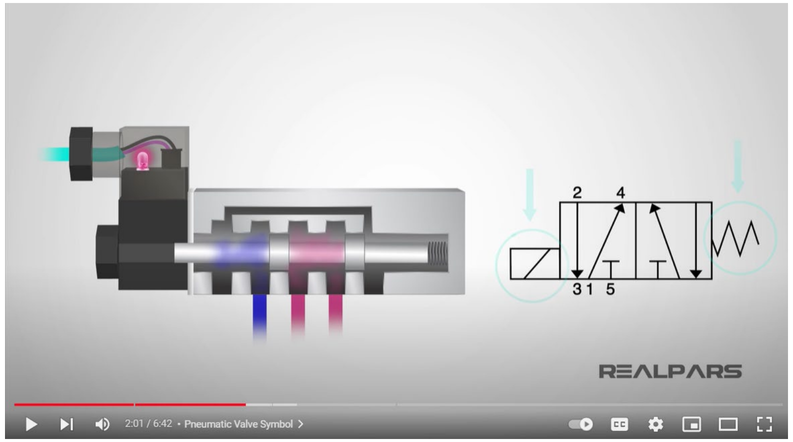
- To block air flow
- To allow air to flow
- To control the speed of air flow
- To control the direction of an actuator
- To sequence an operation

Control Valve Videos



https://www.youtube.com/watch?v=Jfdmrm4A99s

Watch this video for a detailed explanation on how the inside of a valve works.



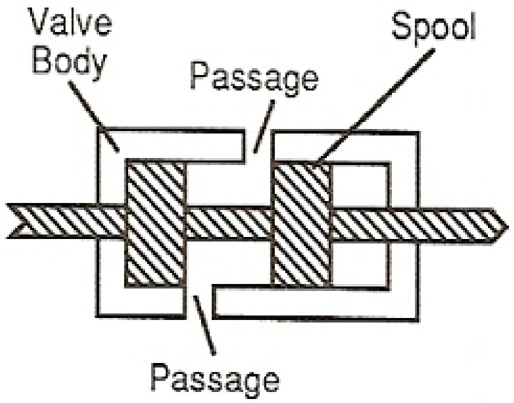
https://www.youtube.com/watch?v=YppUetnI-6M

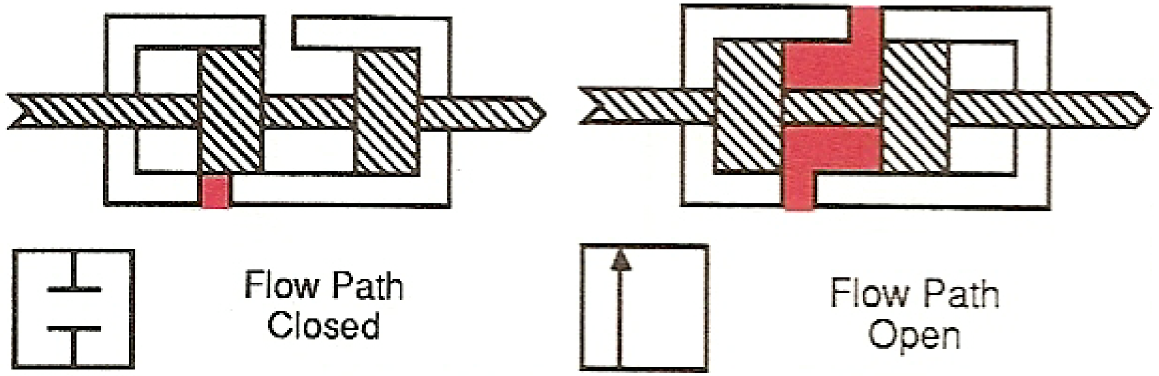
Watch this video to see how a spool valve is represented in a valve schematic

Control Valves

A 2/2 directional valves gives ON-OFF function.
This function is used in a system to:

- Serve as an interlock
- Isolate the system
- Connect various system parts

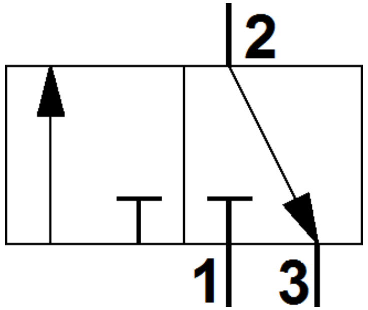




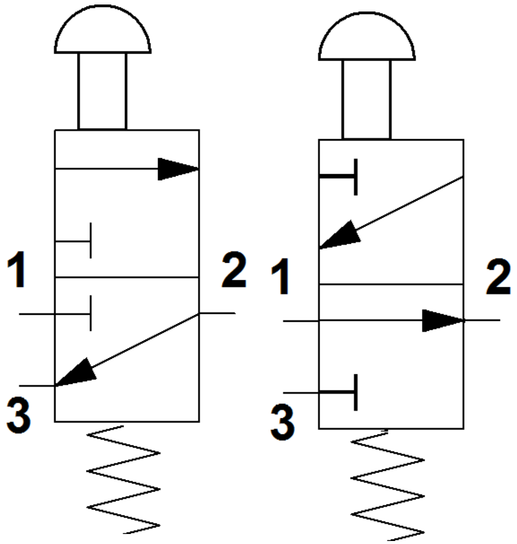
3/2 Control Valves

3/2 valves consist of 3 ports and 2 positions

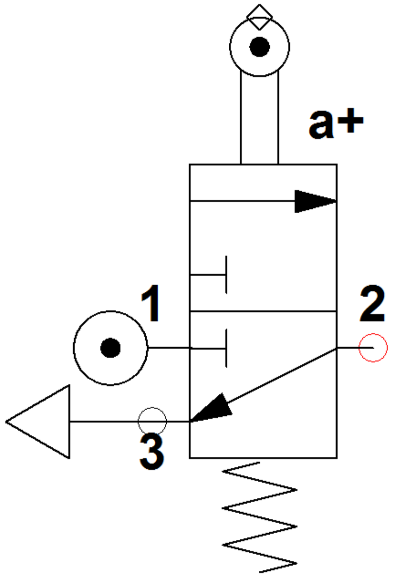
Can be used as:
Push Button Valves
Limit Valve
Single acting cylinder control



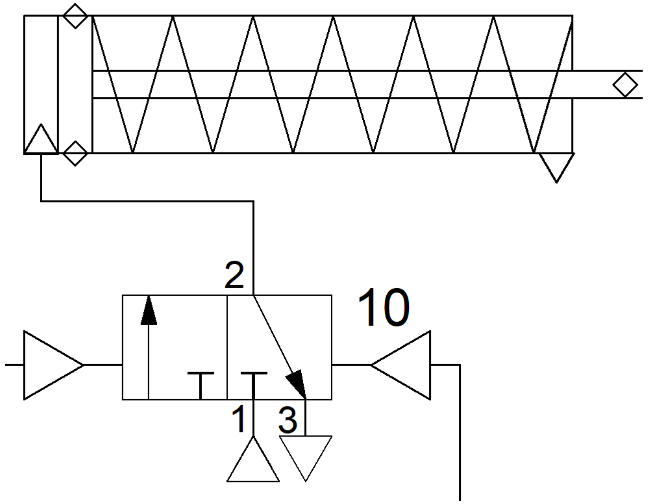
Schematic Symbol



NC and NO Pushbuttons



Limit Valves



Single Acting
Cylinder Control

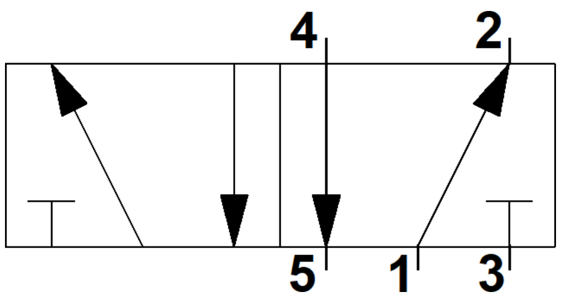
5/2 Control Valves

5/2 valves consist of 5 ports and 2 positions.

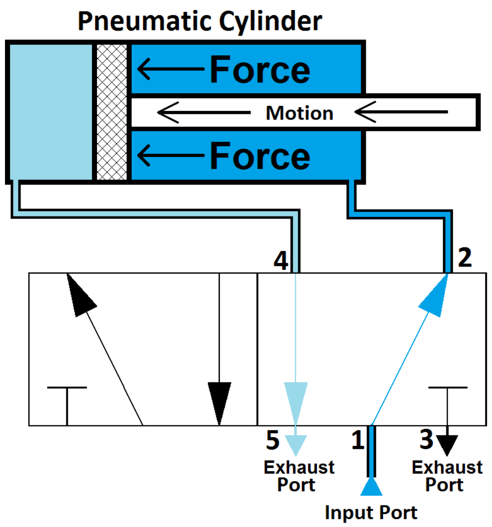
Can be used as:

DCV for double acting cylinder

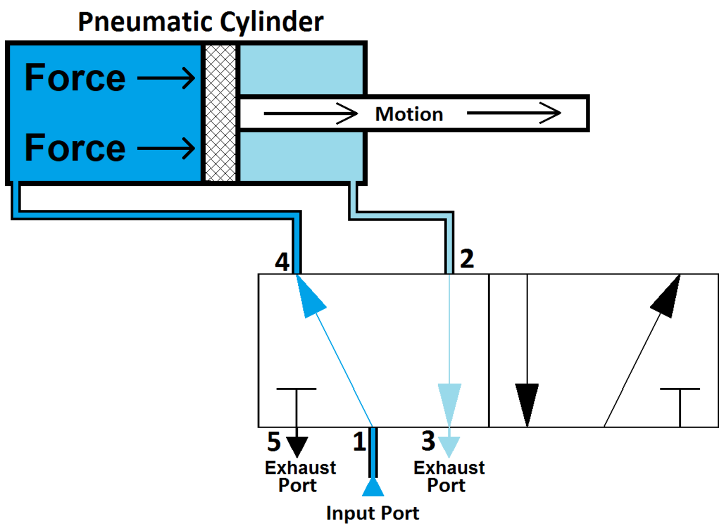
DCV for motor direction



Schematic Symbol



Position 12

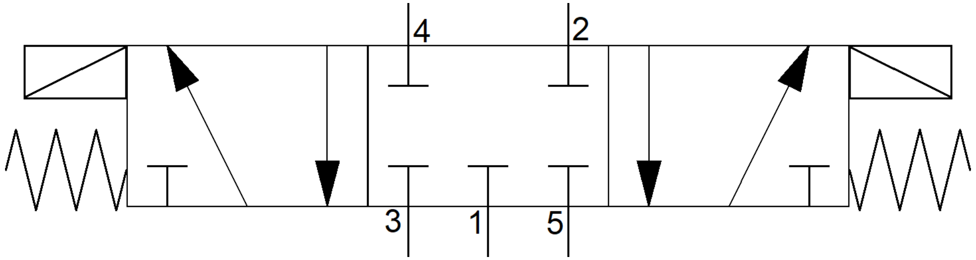


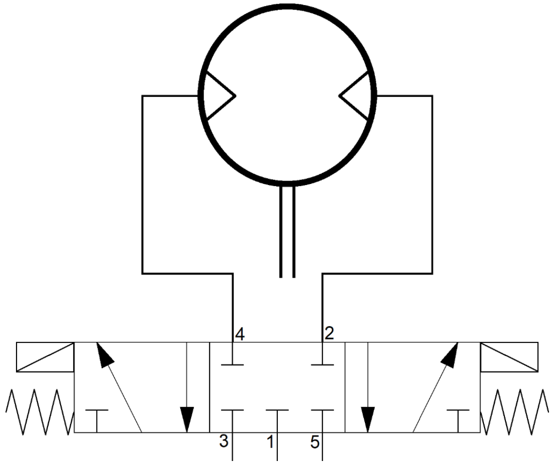
Position 14

5/3 Control Valve

Same function as a 5/2 DCV but
adds a 3rd position, a sprung center position
Center position blocks all ports

Applications:
Stopping a cylinder in mid stroke
Stopping a motor from spinning
'Bumping' (indexing) a cylinder or motor

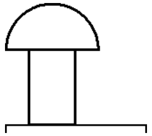




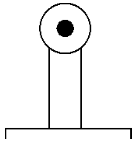
Valve Activation

There are a number of mechanisms that can move the spool in the valve.

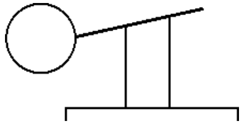
Push Button



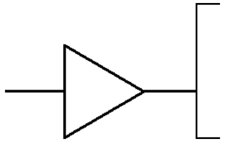
Roller



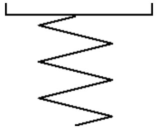
Lever



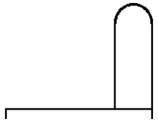
External Pilot



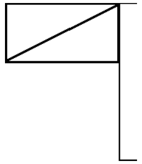
Spring



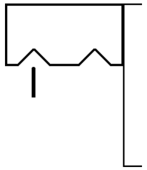
Mechanical



Solenoid



Detent

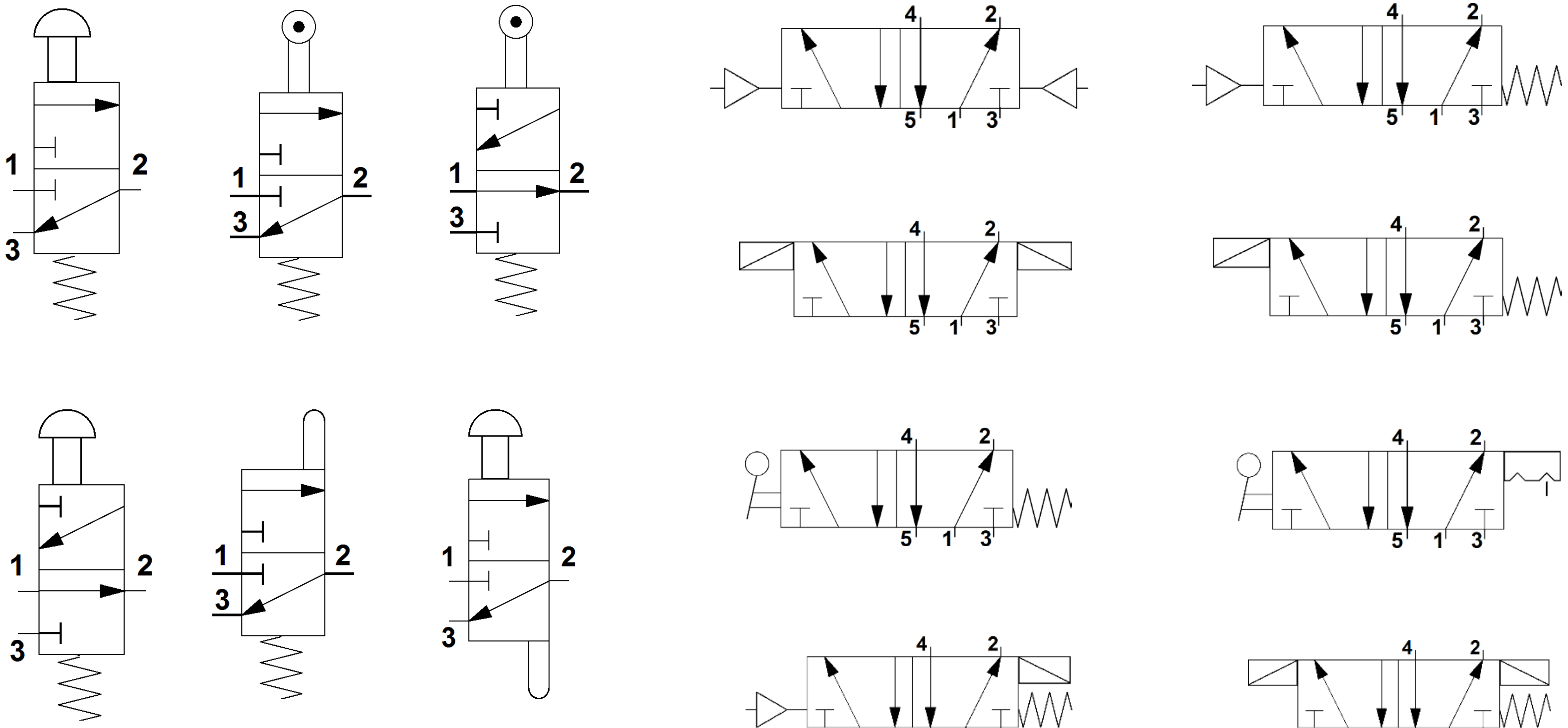


This list goes on… these are common types

Valve Activation Examples

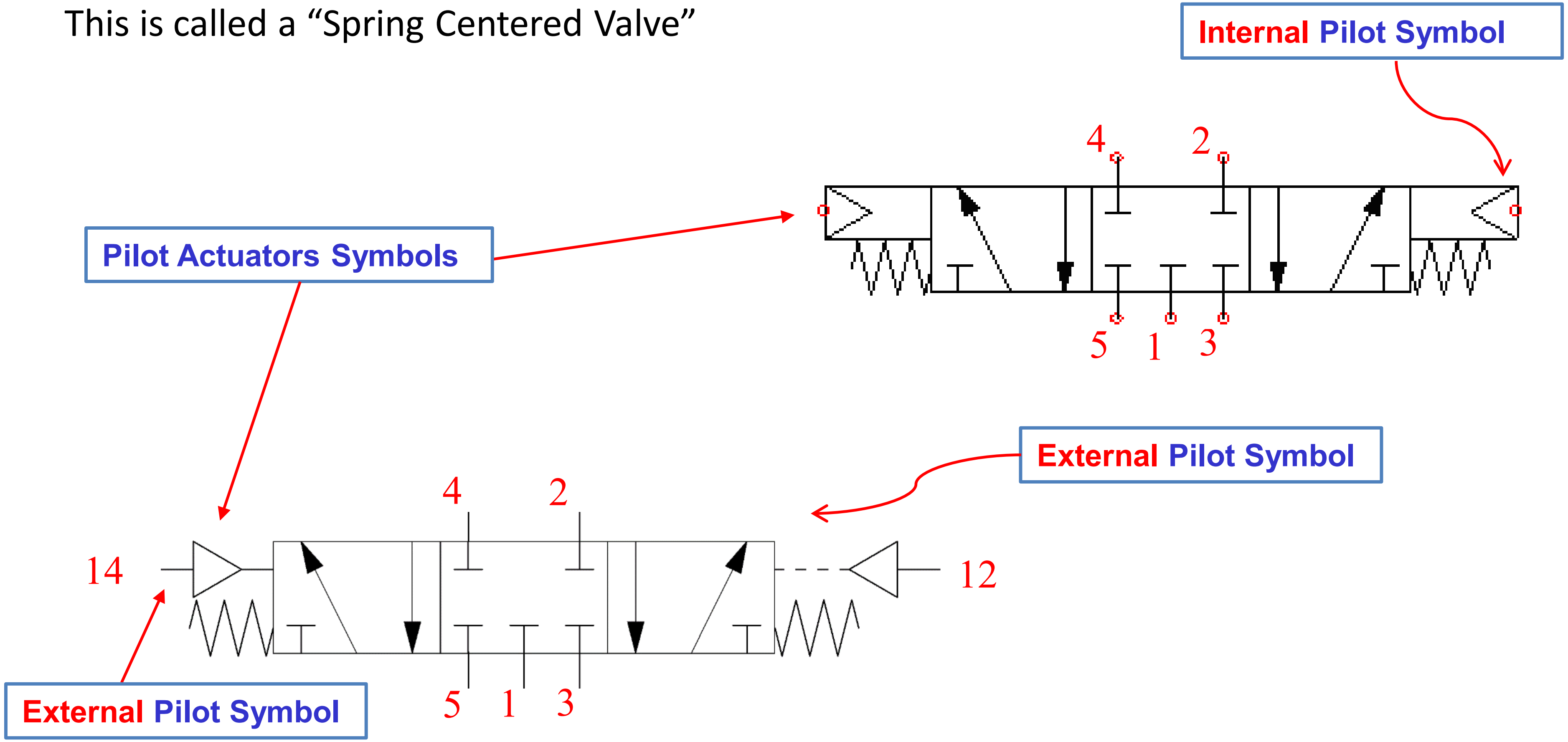
Any valve body type can have any activation type or any combination of activators.

Depending on the operation, a combination of at least two can be used.



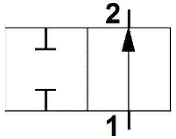
Control Valves & Labeling

- 5/3 valves consist of 5 ports, and 3 positions.
The center position is called the Neutral Position.
This is called a "Spring Centered Valve"

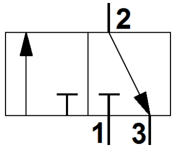


Control Valve Reference Numbers

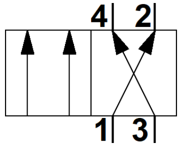
2/2 Valve → 2 Port 2 Position Valve



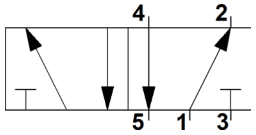
3/2 Valve → 3 Port 2 Position Valve



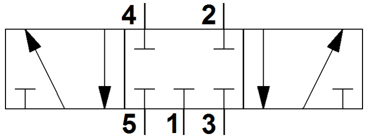
4/2 Valve → 4 Port 2 Position Valve



5/2 Valve → 5 Port 2 Position Valve



5/3 Valve → 5 Port 3 Position Valve



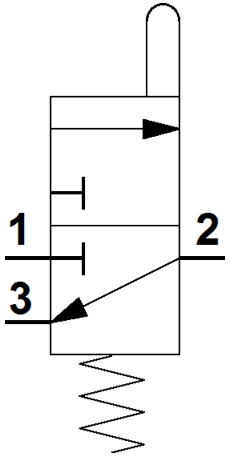
Port Identifications – ISO Standard

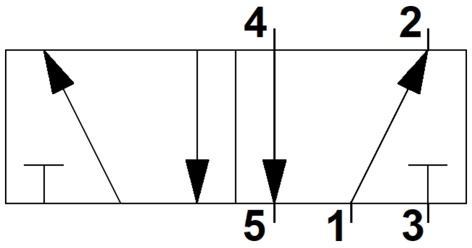
Using Numbers:

ISO 1172 international standard for hydraulics and pneumatics

Valve type[a]	Description	Main ports		
		Inlet(s)	Outlet(s)	Exhaust(s)
2/2	Two-port	1	2	–
3/2 NC	Three-port NC	1	2	3
3/2 NO	Three-port NO	1	2	3
3/2 NO	(Optional)[b]	3	2	1
3/2	Diverter	2	1, 3	–
3/2	Selector	1, 3	2	–
4/2 & 4/3	Four-port	1	2, 4	3
5/2 & 5/3	Five-port	1	2, 4	3, 5
5/2 & 5/3	Five-port[b] (Optional dual pressure)	3, 5	2, 4	1

https://fluidpowerjournal.com/





Port Identifications - Letters

Some manufactures and those drawing fluid power symbols use Letters instead of ISO numbers. Either ISO numbering or lettering is acceptable.

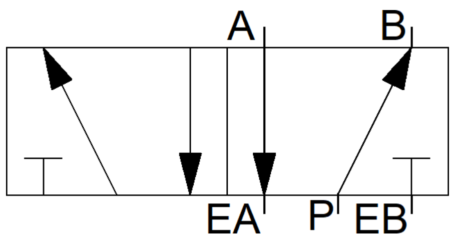
ISO numbering is more common in Pneumatics

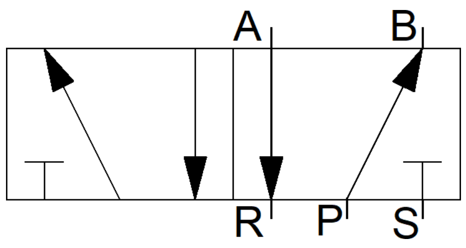
Letters are seen more in Hydraulics

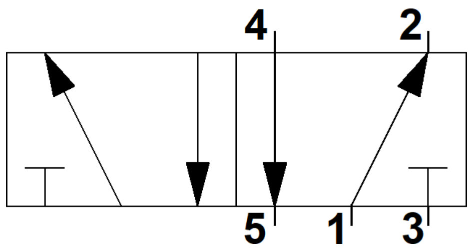
Most Common

- (P) – Pressure Inlet Port
- (A) – Outlet Port
- (B) – Outlet Port
- (R) – Exhaust Port
- (S) – Exhaust Port

Alternative Letters

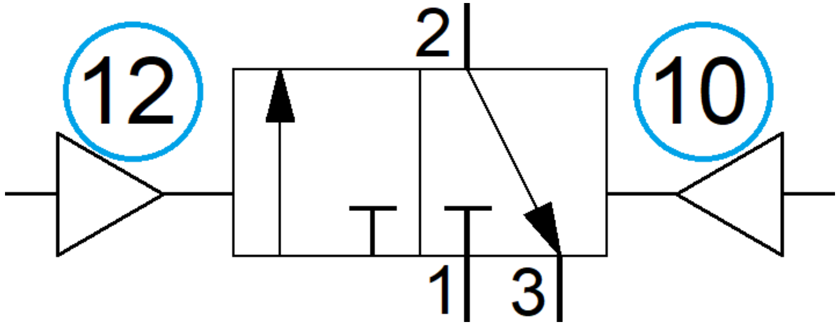






Activation Numbers

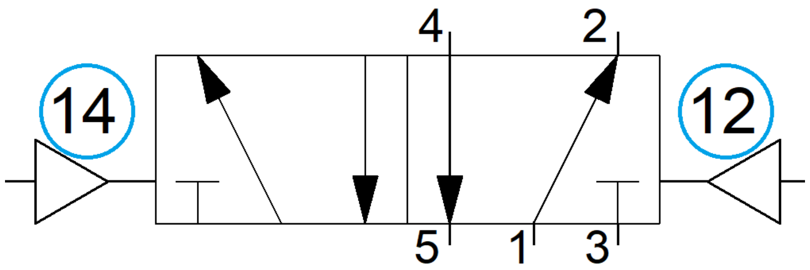
3/2 Valves



When pilot 10 is active, port 1 is blocked

When pilot 12 is active then ports 1 and 2 are connected

5/2 Valves

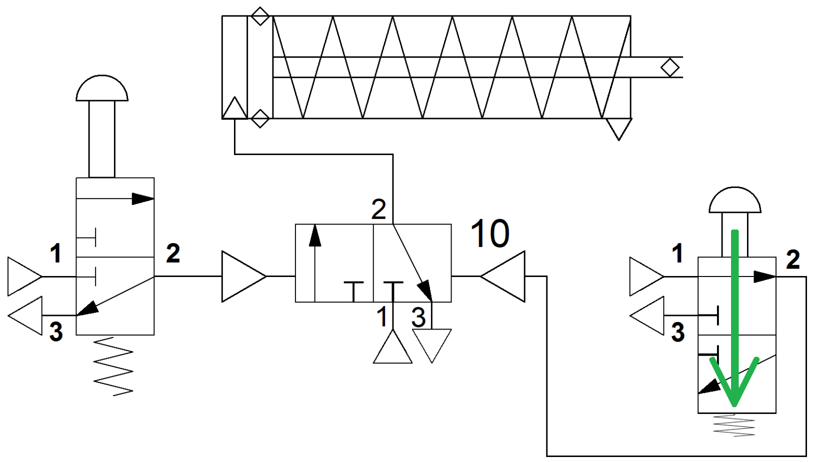


When pilot 12 is active, port 1 and 2 are connected and port 4 and 5 are connected

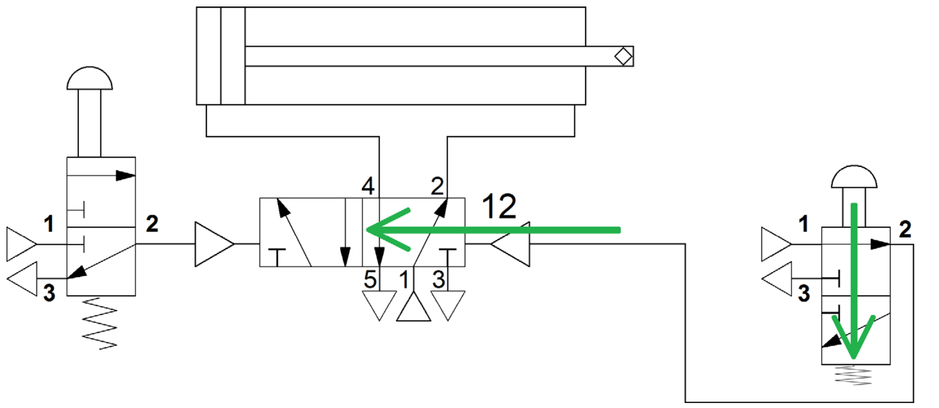
When pilot 14 is active, port 1 and 4 are connected and port 2 and 3 are connected

Activation Numbers

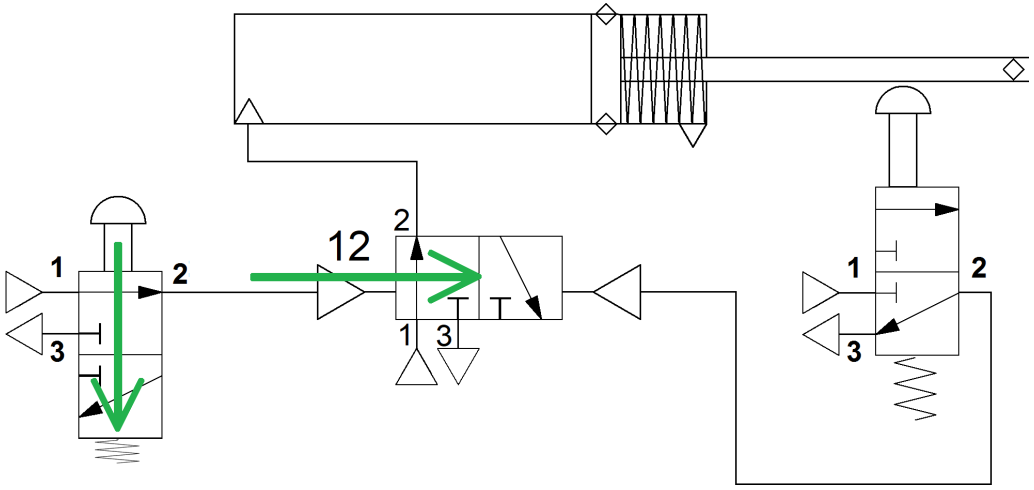
When pilot 10 is active, port 1 is blocked



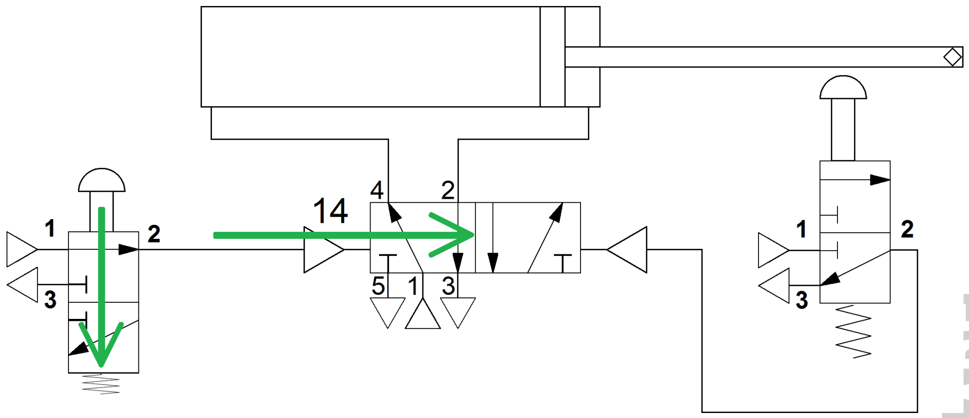
When pilot 12 is active, port 1 and 2 & port 4 and 5 are connected



When pilot 12 is active then ports 1 and 2 are connected



When pilot 14 is active, port 1 and 4 & port 2 and 3 are connected



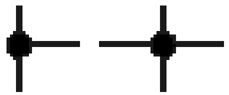
Pneumatic Lines

Working Line used for standard pressure line

Control Line used for pilots or internal control

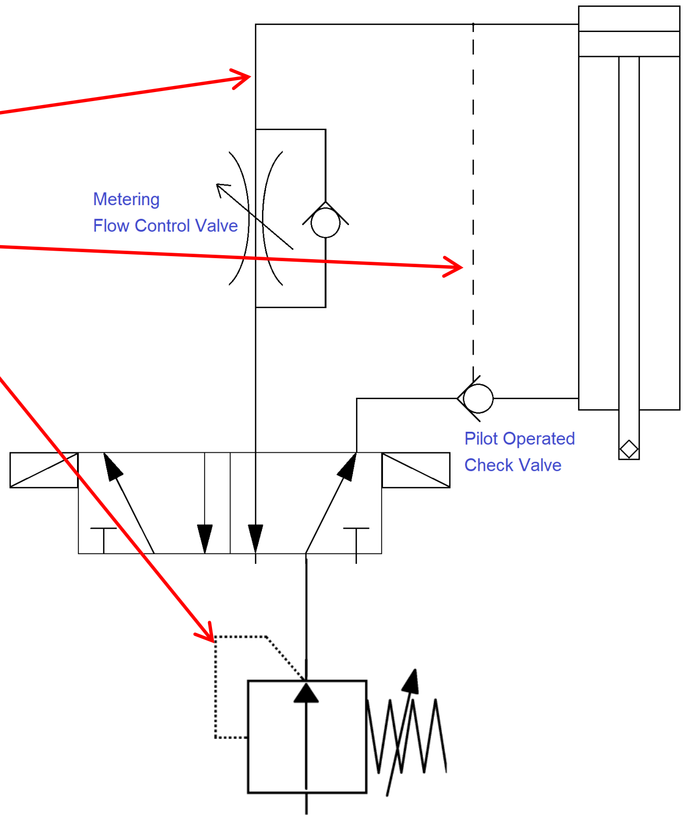
Return Line (Low pressure) used in closed systems such as AC or lab experiments

Flexible Line



Lines Connected

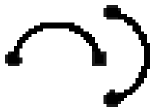
Lines Crossing



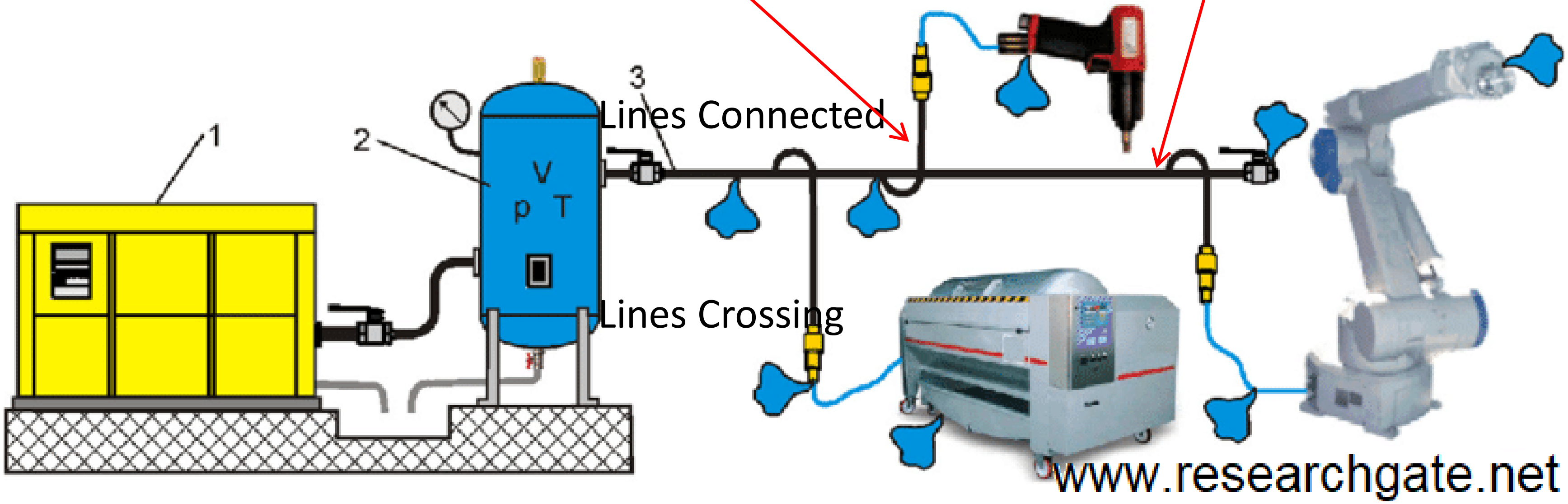
Pneumatic Lines

Rigid Line/pipe: mainly used for air distribution through a facility.

Made from a variety of plastics (e.g. ABS or PCV) or metals (e.g. aluminum or copper)



Flexible Line: used to connect to actuator allowing free movement of actuator. Made of polyurethane, nylon, polyethylene, and polyvinyl chloride (PVC)



Chapter Reading

Chapter 13

13.7-13.9