Pneumatic Systems

For control and automation

Contents

At the end of this class, you will learn

- Basic of pneumatic systems, Gas laws
- Components of pneumatics systems
- Symbols
- Circuit layout
- Actuator control 2/2 Valve
- Actuator control 3/2 Valve
- Actuator control 5/2 Valve
- Sequential control
- Sequence solution
- 5/3 Valves
- Poppet/spool logic
- Balanced spool logic

Introduction

- This module will describe the basics of pneumatics and will show the methods of application of pneumatic valves and components for control and automation
- The methods of pure pneumatic sequential control are confined to simple examples
- The majority of modern systems are controlled electronically and is the subject of electro-pneumatic modules

- **A message to pneumatic circuit designers:**
  - **Use proven and reliable design techniques**
  - **Produce circuits and documentation that are clear to read**
  - **Design for safety**
  - **Do not try to be too clever, the circuit will be difficult for others to read and maintain**

Basics of Pneumatics:

Air: The earth is surrounded by air, 78% Nitrogen, 21% Oxygen and 1% trace gases.

The atmosphere has 12 mile thick envelop of air.

Due to the compressibility of air, increasing the pressure causes decrease in the volume of air.

Gas Laws:

Boyle/Marriot's law: If temperature remains constant, the product of pressure and volume of a particular quantity of gas is constant. PV = C.

Charles's law: If pressure remains constant, the volume of gas is proportional to temperature. $\frac{V1}{V2} = \frac{T1}{T2}$

Gas Laws (contd.):

Lussac's law: If volume remains constant, the pressure of a particular quantity of gas is directly proportional to its absolute temperature. $\frac{p1}{p2} = \frac{T1}{T2}$

General Gas law: Combination of all is the general law as $\frac{p1\,V1}{T1} = \frac{p2\,V2}{T2}$.

There are a few advantages if using compressed air as a source are:

1. Cleanliness
2. Pressure is transmitted undiminished in all direction throughout the system
3. Low cost
4. The best solution for the jig and fixture systems, automation lines, pick and place in electronics industry.

A disadvantage: Typical maximum pressure for a pneumatic system is 7 to 10 bars. This indicates that the pneumatic system are not suitable for the heavy duty in terms of load.

Bar: The bar is defined using the SI derived unit, pascal:

1 bar ≡ 100,000 Pa ≡ 100,000 N/m^2.

Thus, 1 bar is equal to:

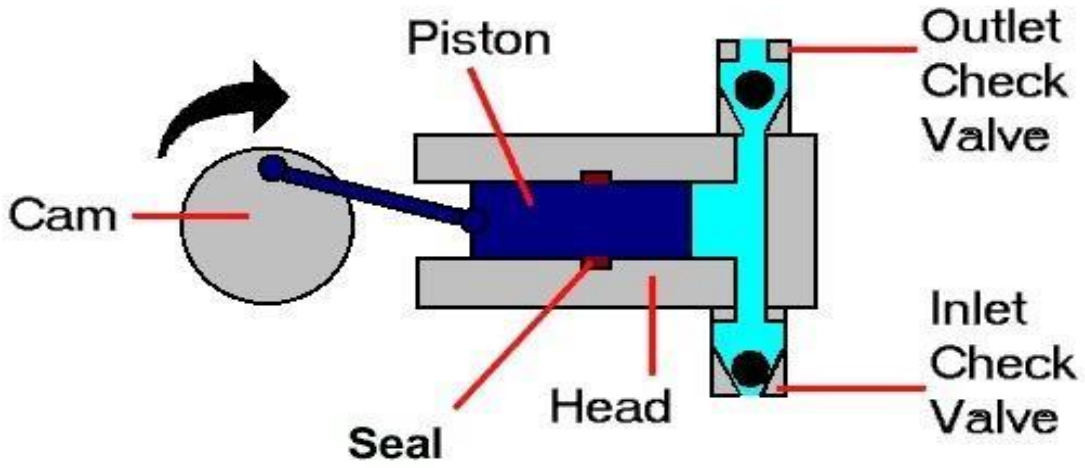
- 1,000,000 Ba (barye) (in cgs units);

1 bar is approximately equal to:

- 0.987 atm
- 14.5038 psi absolute
- 29.53 inHg
- 750.06 mmHg
- 750.06 Torr
- 1019.72 centimetres of water (cmH_2O).

Compressors: **It is a machine that compresses air or another type of gas from a low inlet pressure (usually atmosphere) to a higher desired pressure level. This is achieved by reducing the volume of the gas.**

Air compressors are either reciprocating piston type of the rotary screw type.



SINGLE ACTING RECIPROCATING

The Air capacity of air compressors are generally rated at actual atmospheric conditions. The equation used for the calculation is $V1 = \frac{p2 * V2 * T1}{p1 * T2}$.

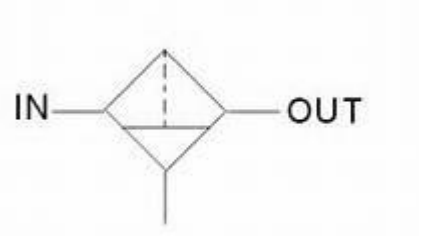
Power required to drive compressors:

$$\text{kW required} = \frac{p_{in}\,Q}{17.1}\left[\left(\frac{p_{in}}{p_{out}}\right)^{0.286} - 1\right]$$

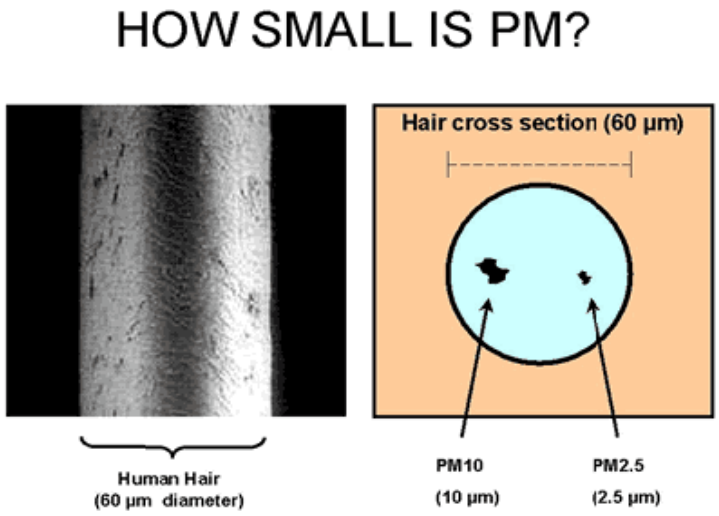
p_{in} is the inlet atmospheric pressure (psia, kPa abs)
p_{out} is the outlet atmospheric pressure, (psia, kPa abs)
Q is flow rate (SCFM, standard m3/min)

Air Filter:

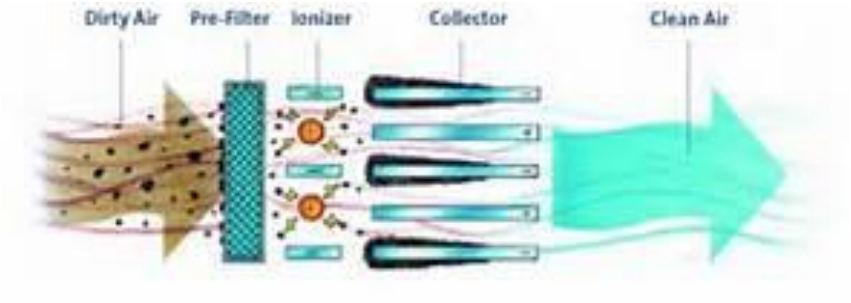
The inlet air is filtered before it is used. The air needs to be free of moisture and contamination. The air filters are used to remove the contaminated particles as small as possible (5 microns and less)

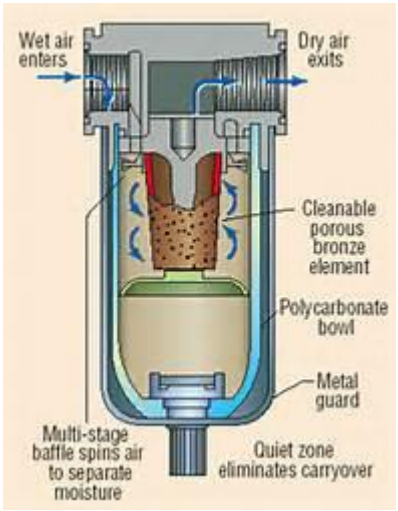


Particulate matter, or PM, is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Particles can be suspended in the air for long periods of time. Some particles are large or dark enough to be seen as soot or smoke. Others are so small that individually they can only be detected with an electron microscope.



Operating principle of Air Filter





The size of a air reservoir is given by

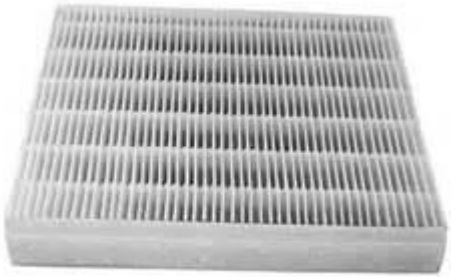
$$V_r = \frac{101\ t\ (Q_r - Q_c)}{p_{max} - p_{min}}$$

Where, Vr = reservoir size,
t = times that the reservoir can supply required amount of air (min)
Qr = consumption rate of pneumatic system (m3/min)
Qc = output flow rate of compressor (m3/min)
Pmax = maximum pressure level in reservoir (kPa)
Pmin = minimum pressure level in reservoir (kPa)

Some available air filters in the market

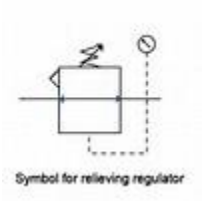


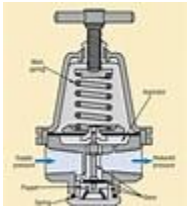


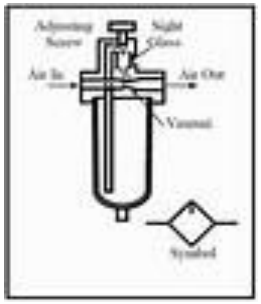


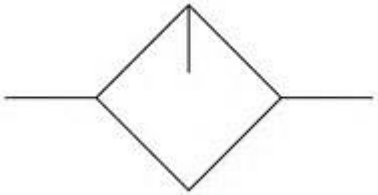
Air pressure regulator: The function is to adjust the pressure of the pneumatic system



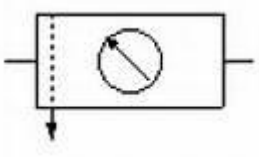


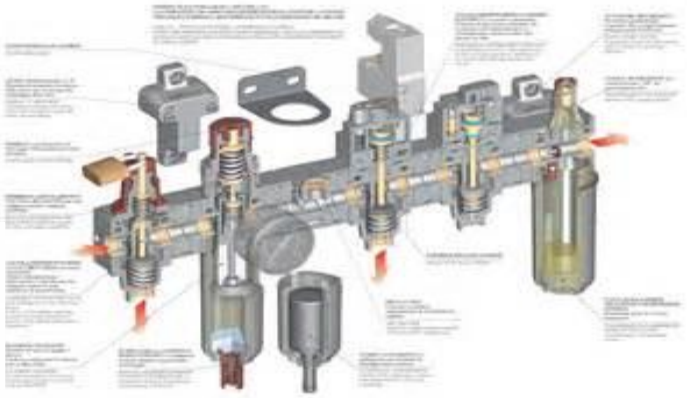
Air Lubricator: The function is to ensure proper lubrication of the pneumatic system.



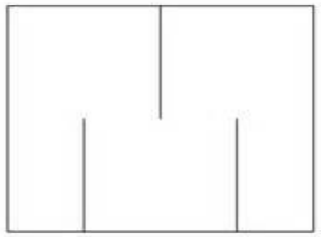


Air service unit: The function is to ensure preparation of optimum compressed air for a specific pneumatic system

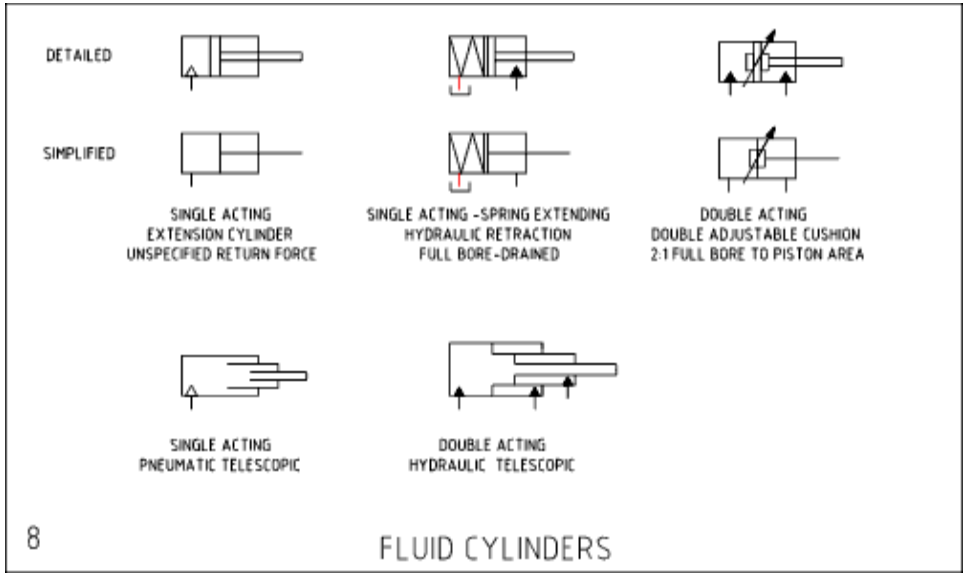




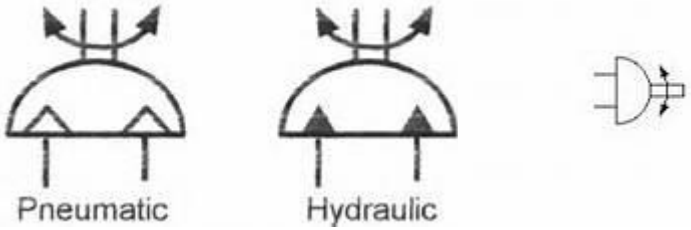
Pneumatic silencer: A silencer may be used to decrease the noise in the outlet of valves. Usually they are made from the porous plastic or bronze.



Pneumatic cylinder: The cylinders convert the energy of the compressed air into linear motion which extend or retract the piston rod.



Pneumatic Rotary Actuator: The rotary actuators convert the energy of the compressed air into rotary motion. Most of them are Vane air motor.

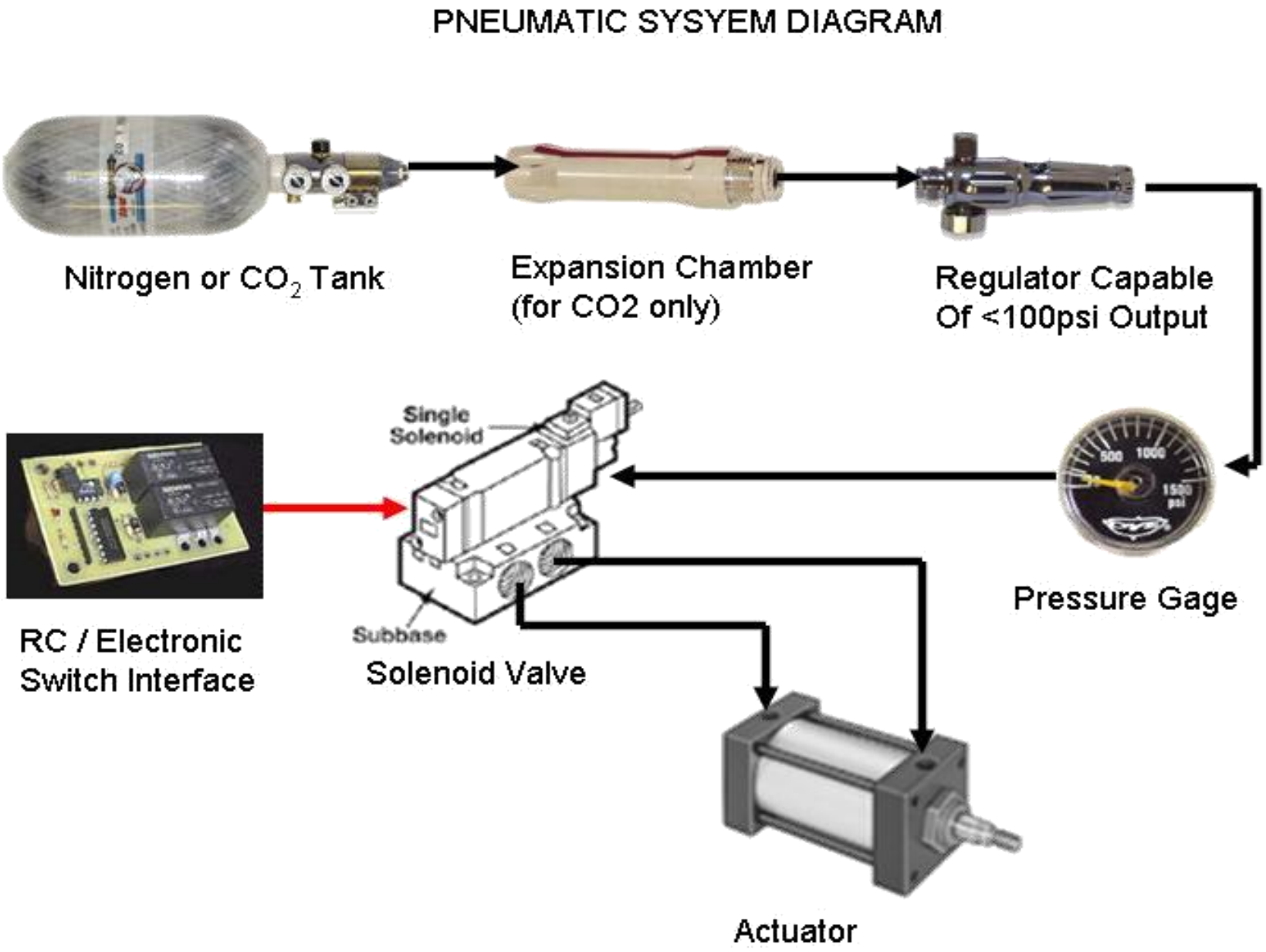


Pneumatic Valves: The valves are used to control flow, pressure and direction of airflow.

Pipes in pneumatic systems

Pipe materials and size: Air systems are normally plumbed with Schedule 40 black iron pipe. (Galvanized pipe is not recommended because some galvanizing material may flake off and get into moving parts.) Several other available plumbing materials could be used for air piping because pressure is relatively low. Some mechanics recommend plastic pipe, but be aware a few synthetic compressor lubricants attack plastic and cause it to lose strength. This type of damage weakens the plastic until it can burst, sending shards of plastic flying everywhere in the plant. Never use any piping material not specifically designated by code.

A Typical Pneumatic System



Actuating systems: Either it can be manual or solenoid based.

Air pressure losses in pipelines: Due to friction, while air flows through a pipe, it losses energy. The loss of energy shows up as a pressure loss, which can be calculated from Harris formula.

$$p_{loss} = \frac{cLQ^2}{3600\,(CR)d^5}$$

Where

p_{loss} = pressure loss (psi)

c = experimentally determined coefficient

L = length of pipe (ft)

Q = flow rate (SCFM)

CR = Compression ration , pressure in pipe/atmospheric pressure

d = inside diameter of pipe (in)

The coefficient c can be represented as a function of the inside diameter of the pipe as

$$c = \frac{0.1205}{d^{.31}}$$

Consideration of Pneumatic circuit design

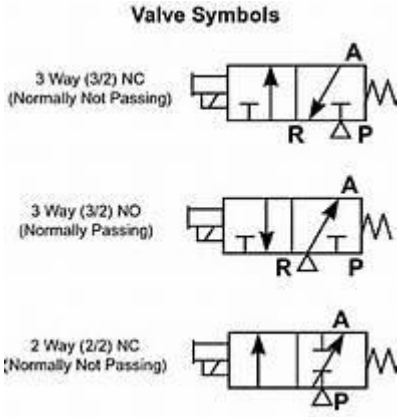
The following four important considerations are taken into account while designing a pneumatic circuit:

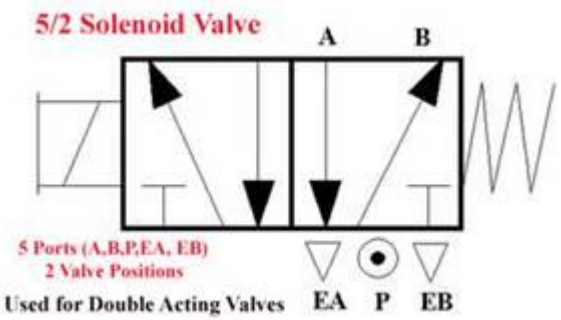
1. **Safety**
2. **Performance**
3. **Efficiency**
4. **Costs**

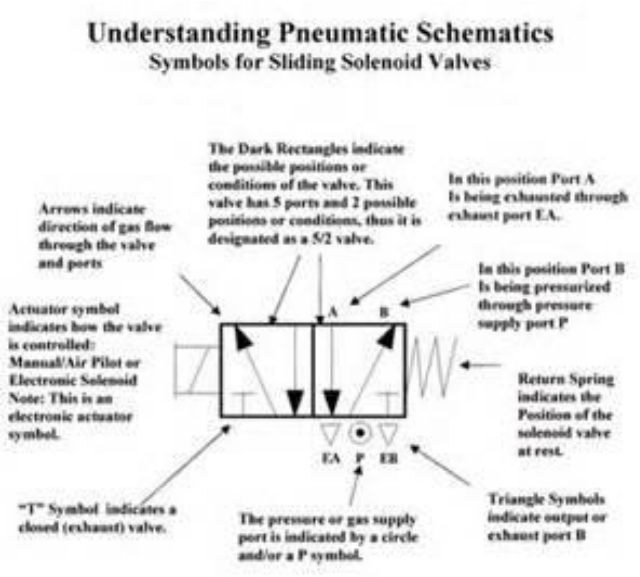
Symbols for Pneumatic circuit design

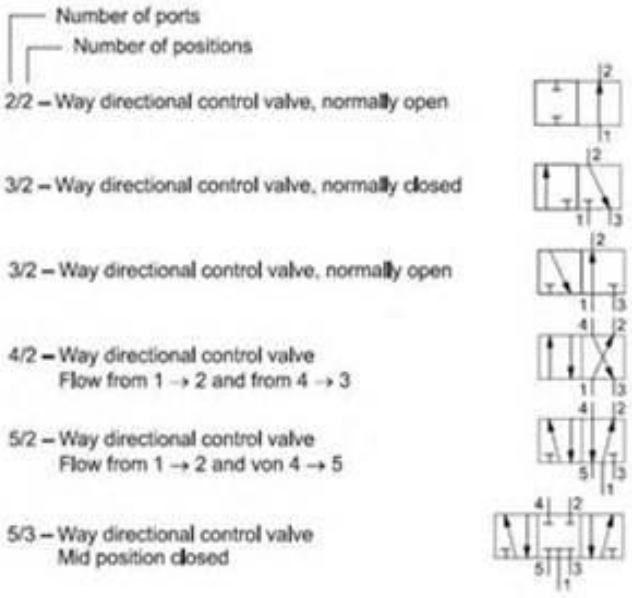
- The standard for fluid power symbols is ISO 1219-1. This is a set of basic shapes and rules for the construction of fluid power symbols
- Cylinders can be drawn to show their extreme or intermediate positions of stroke and any length above their width
- Valves show all states in the one symbol. The prevailing state is shown with the port connections
- Other components are single state symbols

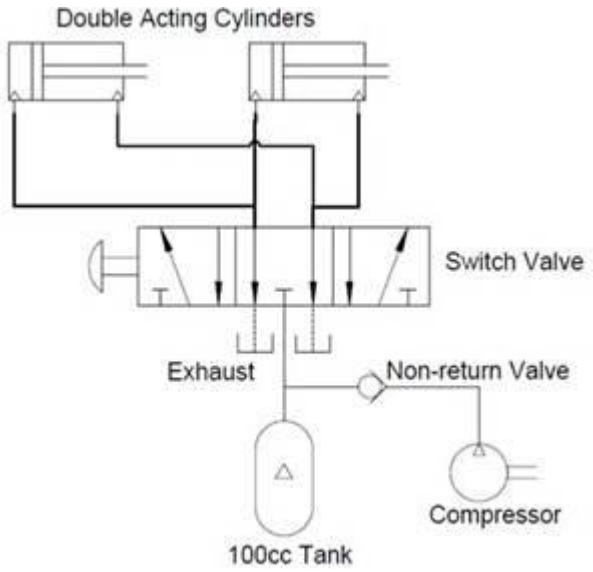
Symbols of pneumatic valve





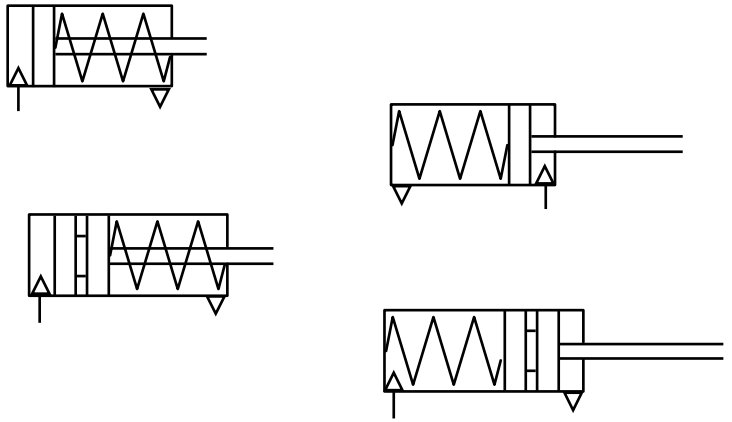






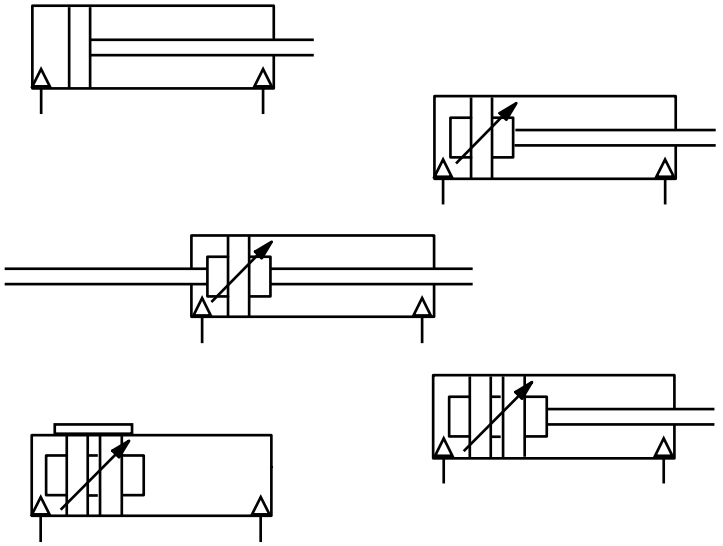
Symbols single acting actuators

- Single acting, sprung instroked
- Single acting, sprung outstroked
- Single acting, sprung instroked, magnetic
- Single acting, sprung outstroked, magnetic



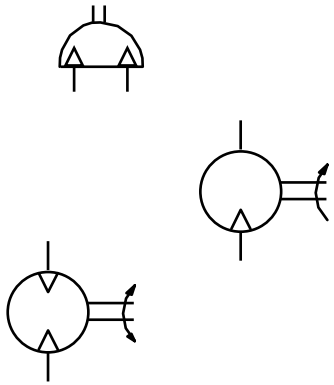
Symbols double acting actuators

- Double acting, non-cushioned
- Double acting, adjustable cushions
- Double acting, through rod, adjustable cushions
- Double acting, magnetic, adjustable cushions
- Double acting, rodless, magnetic, adjustable cushions



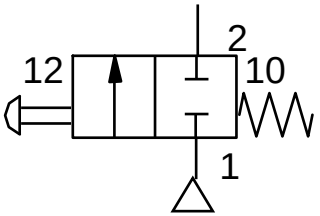
Symbols rotary actuators

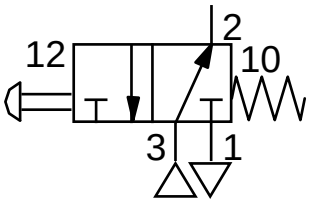
- **Semi-rotary double acting**
- **Rotary motor single direction of rotation**
- **Rotary motor bi-directional**

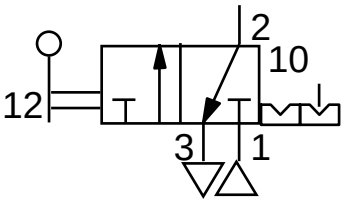


Symbols valves

- **2/2 Valve push button / spring**
- **3/2 Valve push button / spring**
- **3/2 Valve lever operated**

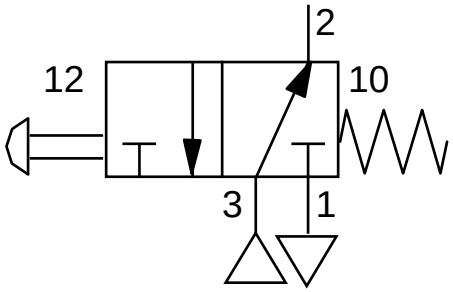






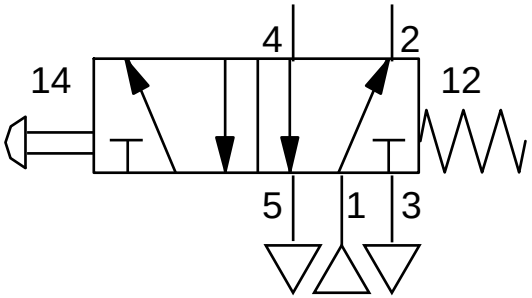
Symbols valves

- A valve function is known by a pair of numbers e.g. 3/2. This indicates the valve has 3 main ports and 2 states
- The valve symbol shows both of the states
- Port numbering is to CETOP RP68P and shows:
  - when the valve is operated at the 12 end port 1 is connected to port 2
  - when reset to the normal state at the 10 end port 1 is connected to nothing (0); port 3 is connected to port 2.



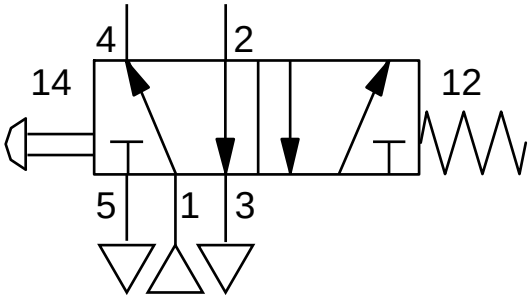
Symbols valves

- **This example is for a 5/2 valve**
- **This has 5 main ports and 2 states**
- **When the valve is operated at the 14 end port 1 is connected to port 4 (also port 2 is connected to port 3)**
- **When reset to the normal state at the 12 end port 1 is connected to port 2 (also port 4 is connected to port 5)**



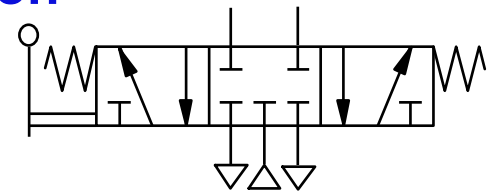
Symbols valves

- This example is for a 5/2 valve
- This has 5 main ports and 2 states
- When the valve is operated at the 14 end port 1 is connected to port 4 (also port 2 is connected to port 3)
- When reset to the normal state at the 12 end port 1 is connected to port 2 (also port 4 is connected to port 5)

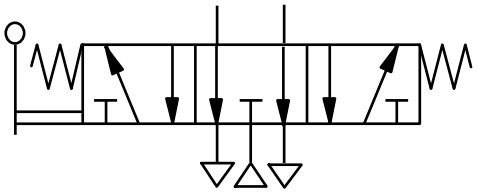


Symbols 5/3 valves

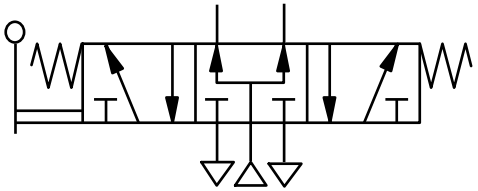
- All valves types shown in the normal position
- Type 1. All ports blocked



- Type 2. Outlets to exhaust

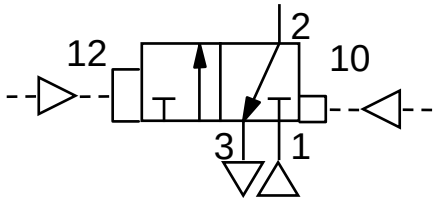


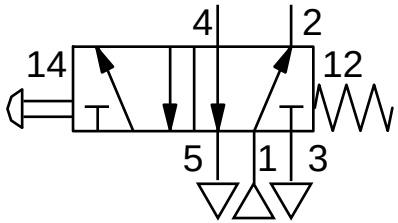
- Type 3. Supply to outlets

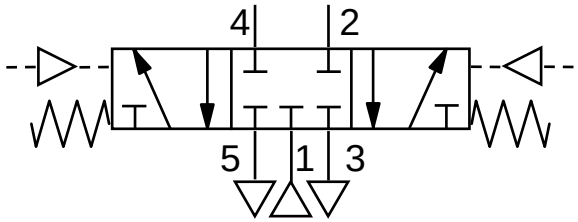


Symbols valves

- **3/2 Valve differential pressure operated**
- **5/2 Valve push button / spring**
- **5/3 Valve double pressure operated spring centre**

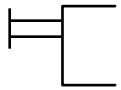




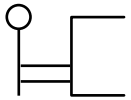


Symbols operators manual

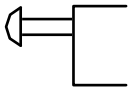
General manual



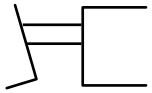
Lever



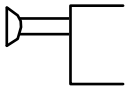
Push button



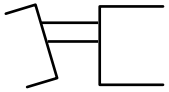
Pedal



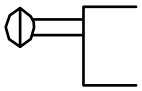
Pull button



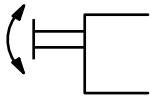
Treadle



Push/pull button

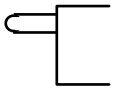


Rotary knob

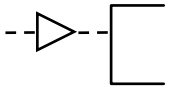


Symbols operators mechanical

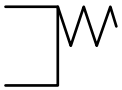
Plunger



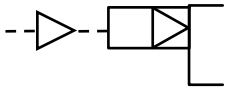
Pressure



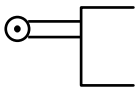
Spring normally as a return



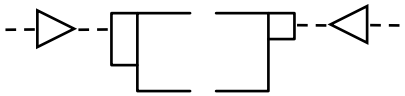
Pilot pressure



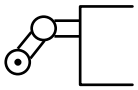
Roller



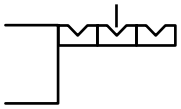
Differential pressure



Uni-direction or one way trip

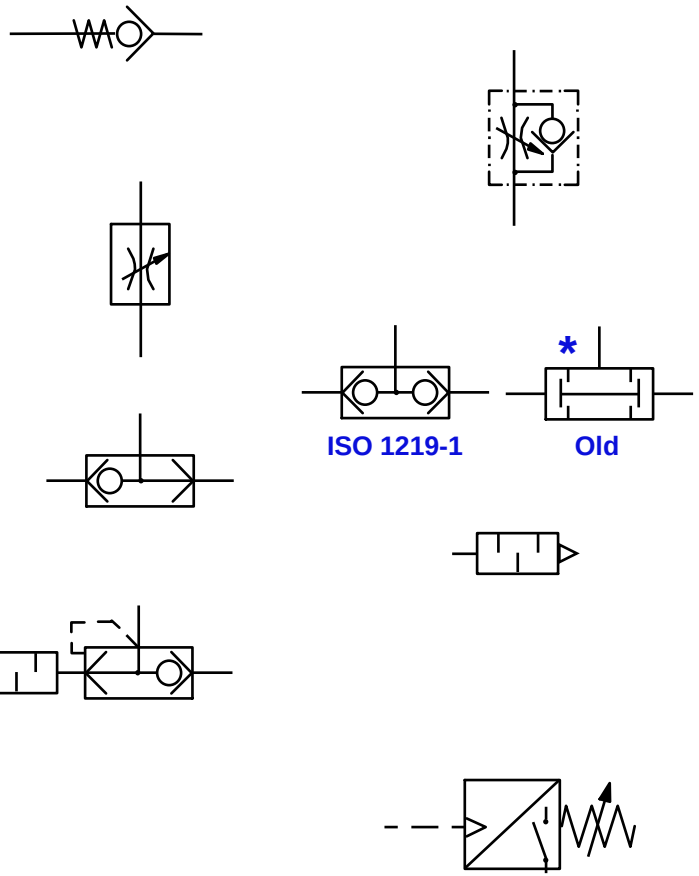


Detent in 3 positions



Symbols function components

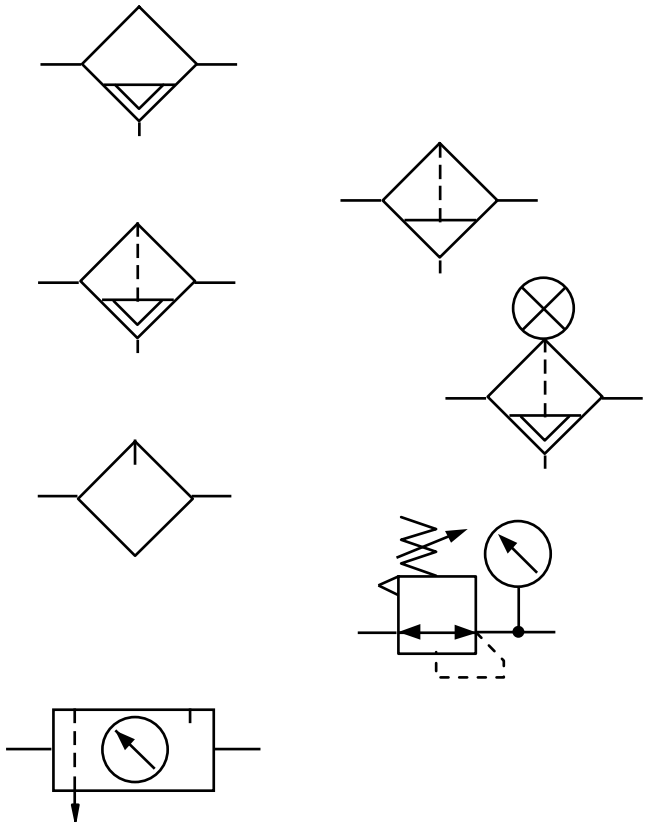
- Non-return valve
- Flow regulator uni-directional
- Flow regulator bi-directional
- Two pressure ‘AND’
- Shuttle valve ‘OR’
- Silencer
- Quick exhaust valve with silencer
- Pressure to electric switch adjustable



* Note: Traditional symbol in extensive use (preferred)

Symbols air line equipment

- **Water separator with automatic drain**
- **Filter with manual drain**
- **Filter with automatic drain**
- **Filter with automatic drain and service indicator**
- **Lubricator**
- **Pressure regulator with gauge**
- **F.R.L. filter, regulator, lubricator simplified symbol**



Circuit layout

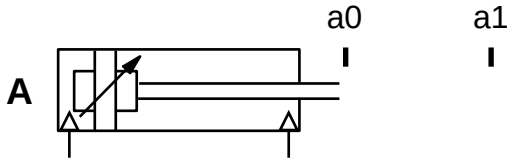
- The standard for circuit diagrams is ISO 1219-2
- A4 format or A3 folded to A4 height for inclusion in a manual with other A4 documentation
- To be on several sheets if necessary with line identification code
- Minimum crossing lines
- Limit valves position of operation by actuators shown by a marker with reference code to symbol

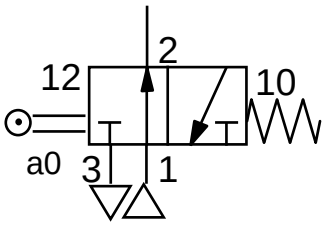
- **Circuits should be drawn with all actuators at the top of the page in order of sequential operation**
- **Other components to be drawn in sequential order from the bottom up and from left to right**
- **Circuit should show the system with pressure applied and ready to start**

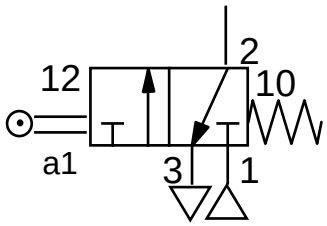
Component identification

- **The ISO suggested component numbering system is suited for large circuits and those drawn on several pages**
- **For this presentation a simple code is used**
- **For cylinders: A,B,C etc.**
- **For associated feedback valves: alpha-numeric code ‘a0’ for proof of instroke, ‘a1’ for proof of outstroke**
- **For cylinder B: b0 and b1**

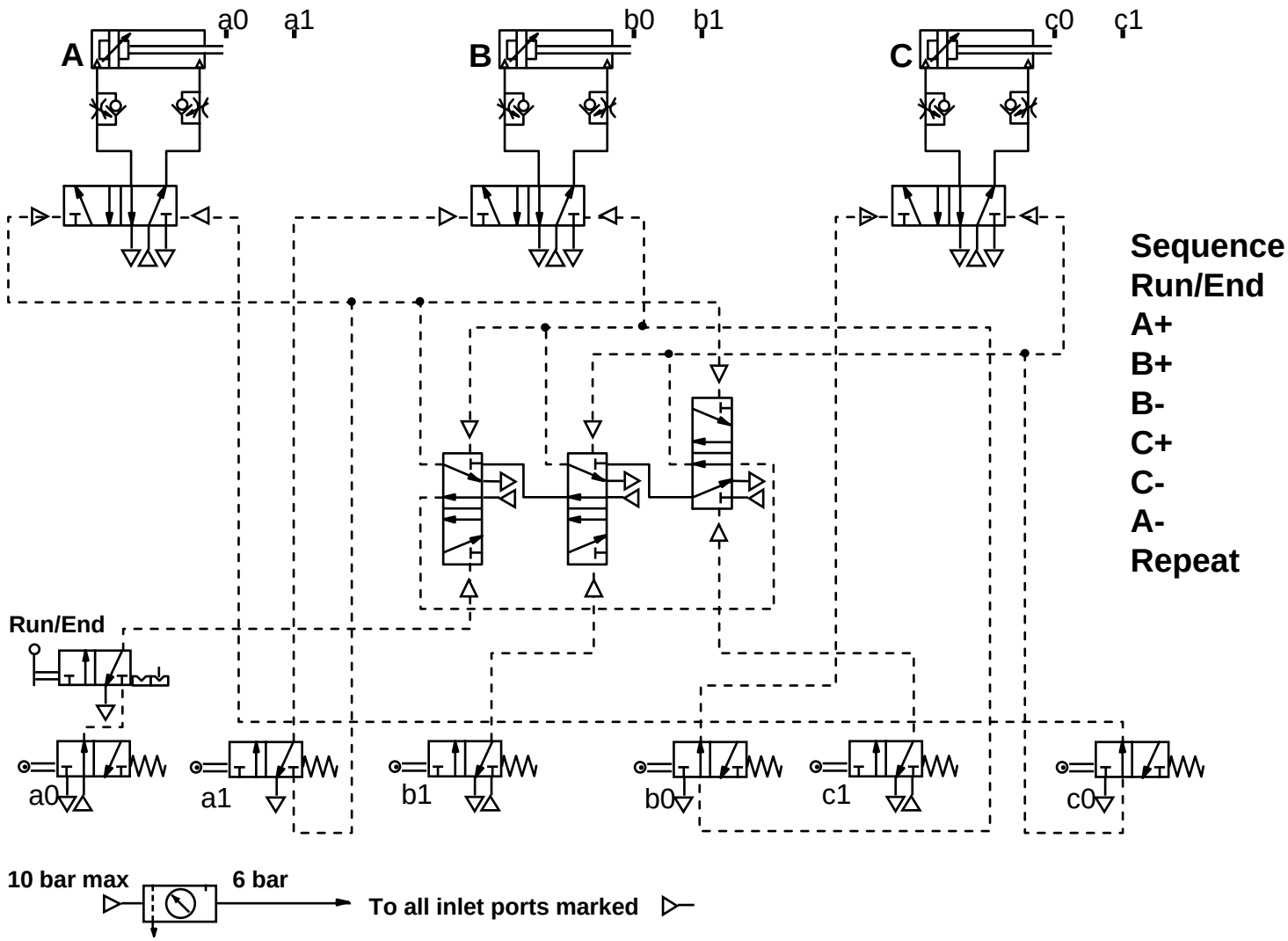
- Note: the a0 valve symbol is drawn in the operated position because the actuator A is instroked







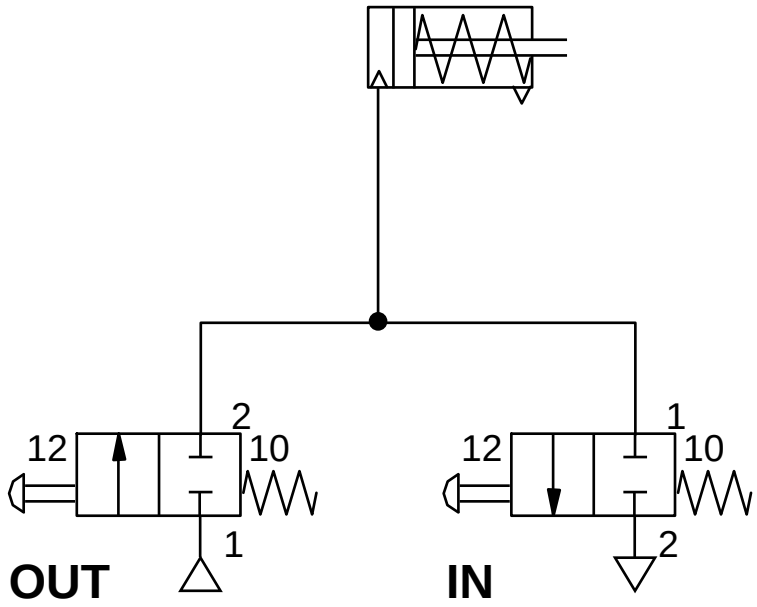
Example circuit



Actuator control 2/2 valve

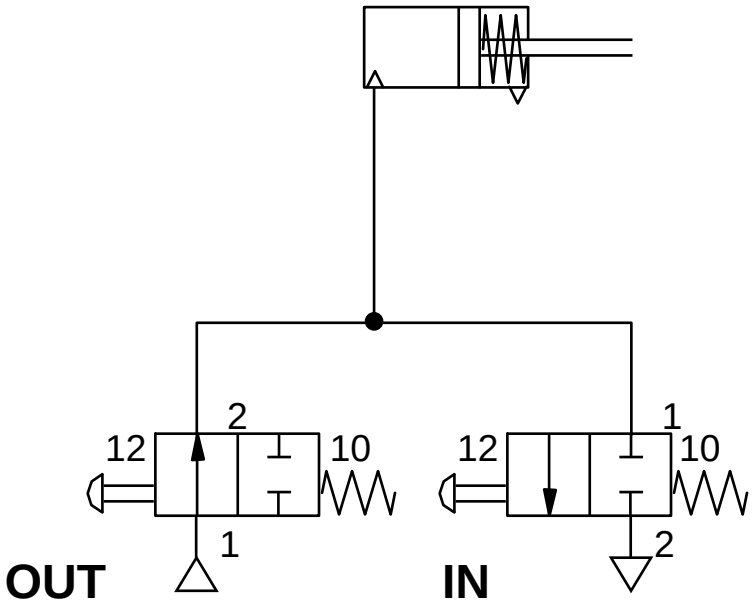
2/2 Valve actuator control

- **A pair of the most basic of all valve types the 2/2 can be used to control a single acting cylinder**
- **The normally closed position of the valve is produced by the spring**
- **The operated position is produced by the push button**
- **One valve admits air the other valve exhausts it**



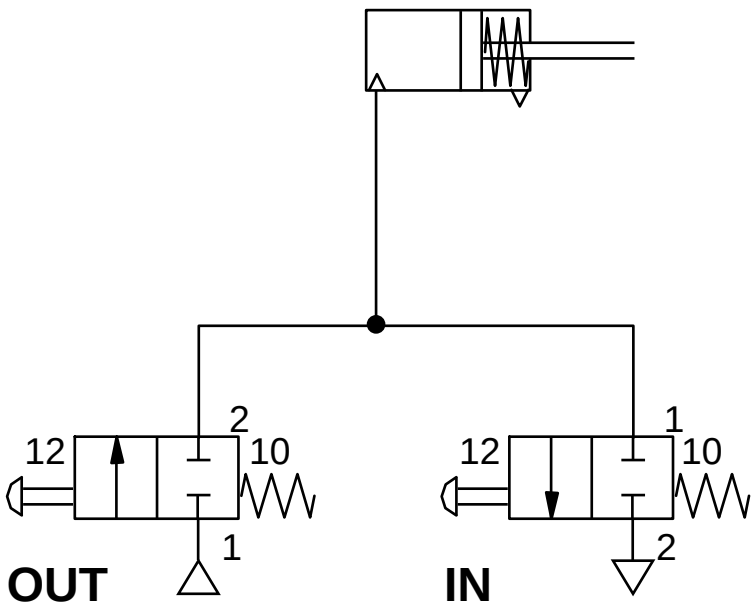
2/2 Valve actuator control

- The button marked OUT is pushed to operate the valve
- Air is connected to the cylinder and it outstrokes
- Air cannot escape to atmosphere through the valve marked IN as this is closed
- The air at atmospheric pressure in the front of the cylinder vents through the breather port



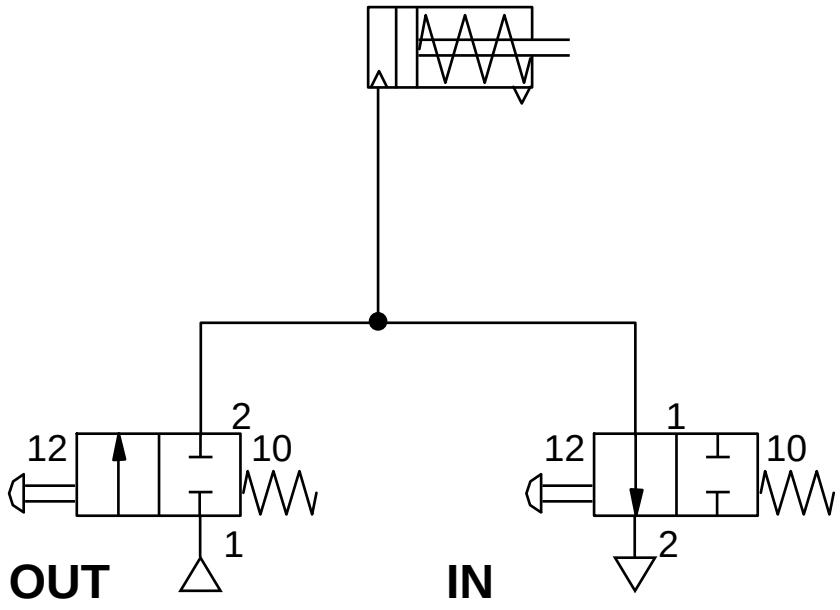
2/2 Valve actuator control

- **The push button of the valve marked OUT is released and it returns to a normal closed position**
- **Air is now trapped in the system and provided there are no leaks the piston rod will stay in the outstroked position**
- **If the load increases beyond the force exerted by the air the piston rod will start to move in**



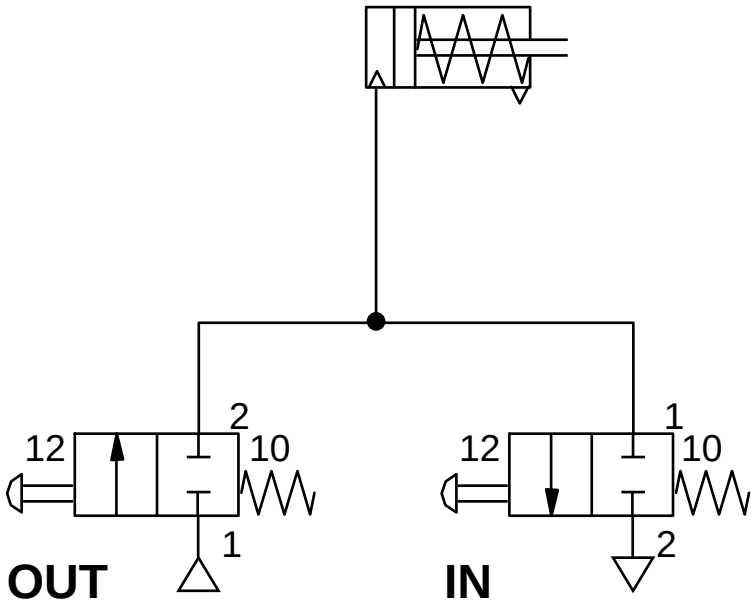
2/2 Valve actuator control

- **The button marked IN is pushed to operate the valve**
- **Air escapes and the piston rod moves to the instroked position**
- **The push button must be held operated until the piston rod is fully in**
- **Atmospheric air will be drawn in to the front of the cylinder through the vent port**



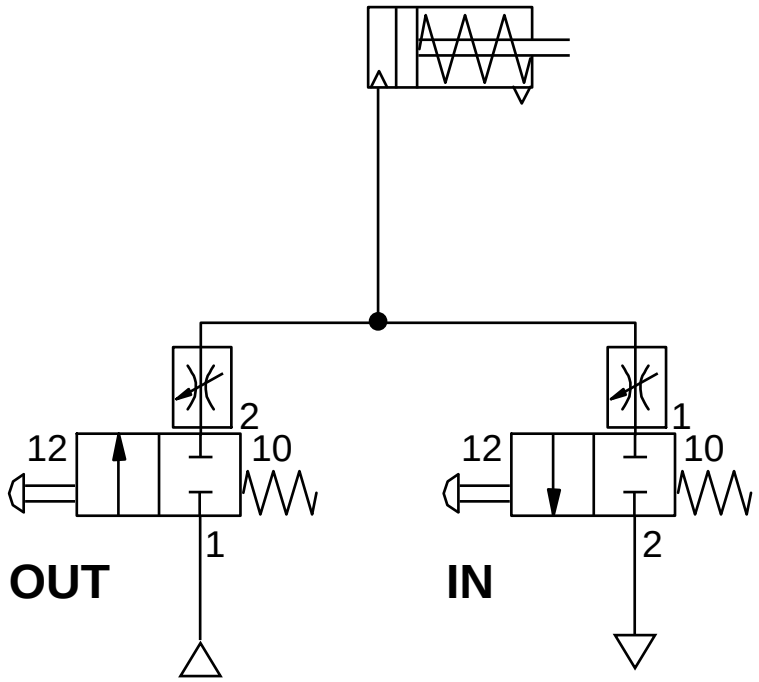
2/2 Valve actuator control

- **If the button marked IN is released the piston rod will remain in the instroked position**
- **Any leaks in the installation can cause the piston rod to creep**



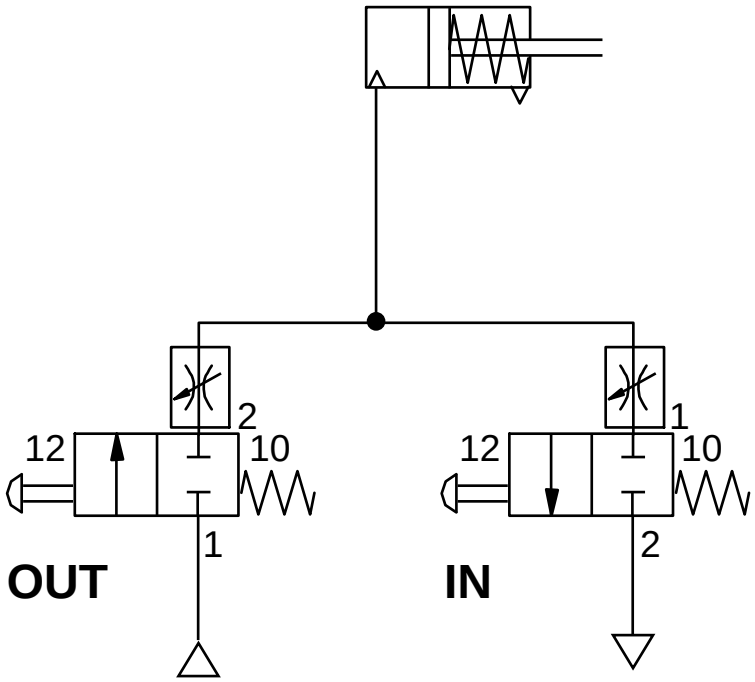
2/2 Valve actuator control

- **To control the speed of the piston rod, flow restrictors are placed in the pipes close to each of the valves.**
- **Adjustment of the restrictors will slow down the flow rate thereby giving independent outstroke and instroke speed control**



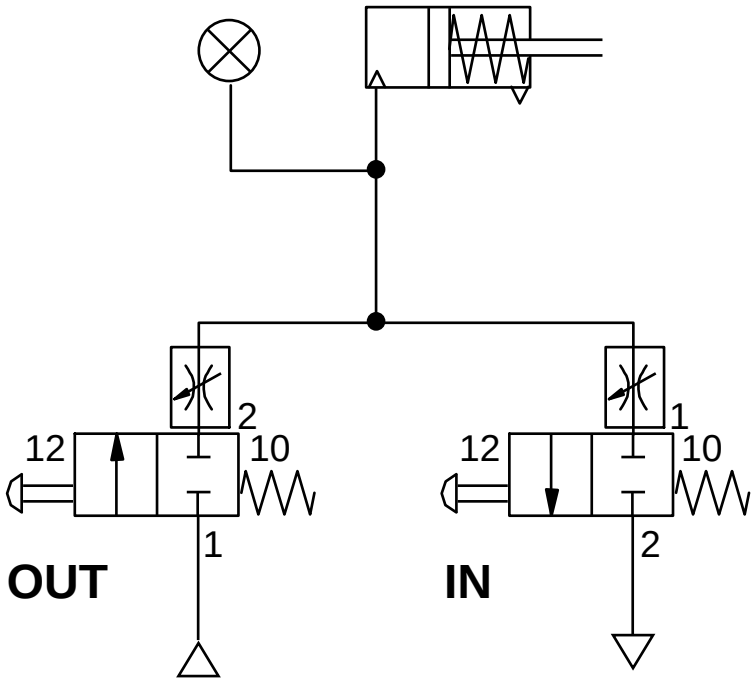
2/2 Valve actuator control

- By repeated operation of either button during movement the piston rod can be moved in small steps for approximate positioning
- This will only be successful under slow speeds



2/2 Valve actuator control

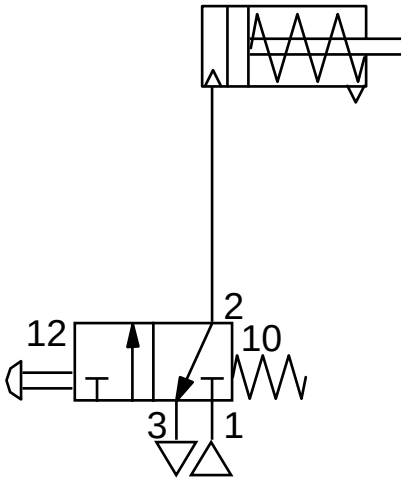
- **With any compressed air system that intentionally traps air, the potential hazard of this must be recognised**
- **Unintended release or application of pressure can give rise to unexpected movement of the piston rod**
- **A pressure indicator or gauge must be fitted to warn of the presence of pressure**



Actuator control 3/2 valve

3/2 valve actuator control

- **A 3 port valve provides the inlet and exhaust path and is the normal choice for the control of a single acting cylinder**
- **In the normal position produced by the spring, the valve is closed**
- **In the operated position produced by the push button the valve is open**
- **The push button must be held down for as long as the cylinder is outstroked**



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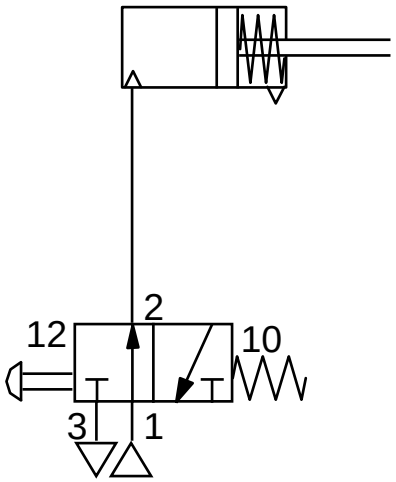

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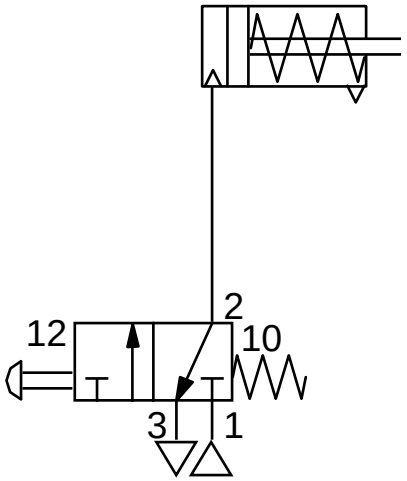
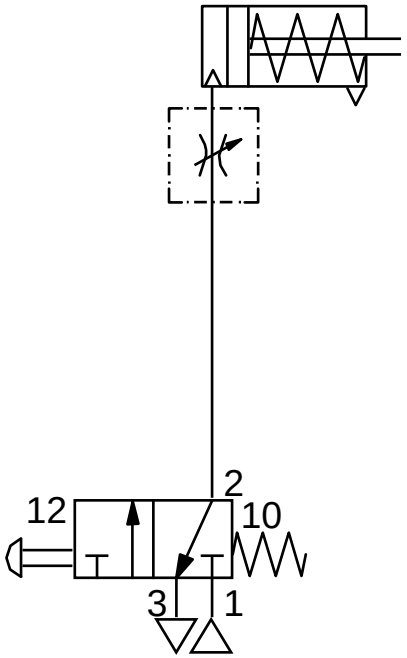


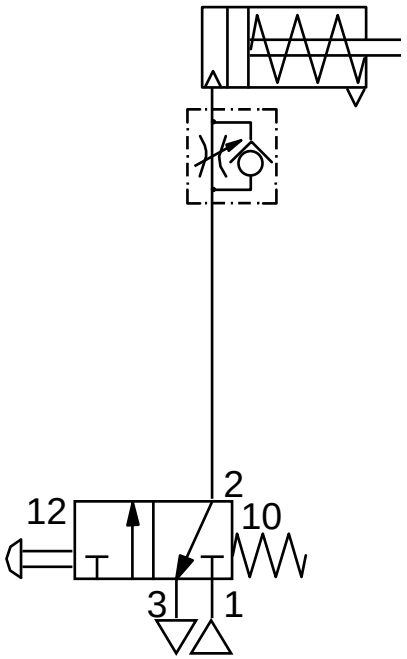
3/2 valve actuator control

- **To generally slow the cylinder speed an adjustable bi-directional flow regulator or fixed restrictor can be used**
- **The flow regulator setting will be a compromise as the ideal outstroke speed may not produce the desired results for the instroke speed**



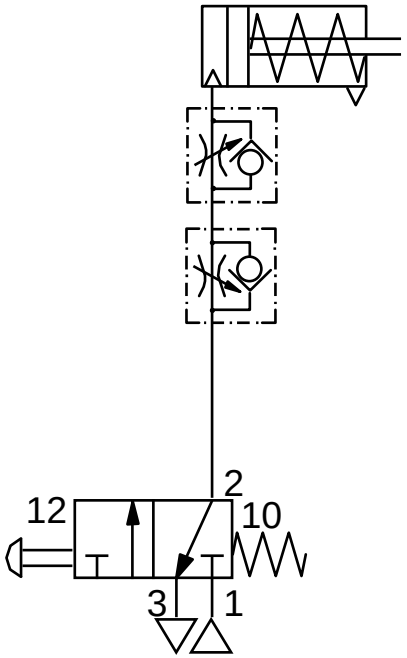
3/2 valve actuator control

- **To control the outstroke speed of a single acting cylinder without controlling the instroke speed, a uni-directional flow regulator is used**
- **The flow into the cylinder closes the non return valve and can only pass through the adjustable restrictor**
- **By adjusting the restrictor the outstroke speed of the cylinder can be set**



3/2 valve actuator control

- For independent speed control in each direction two flow regulators are required
- Installed in opposite directions to each other
- Upper regulator controls the outstroke speed
- Lower regulator controls the instroking speed



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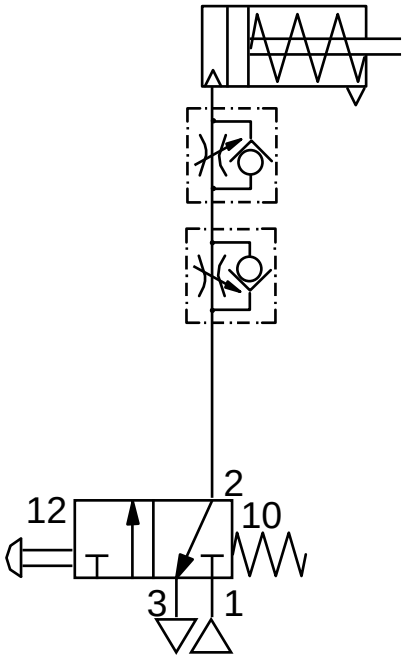
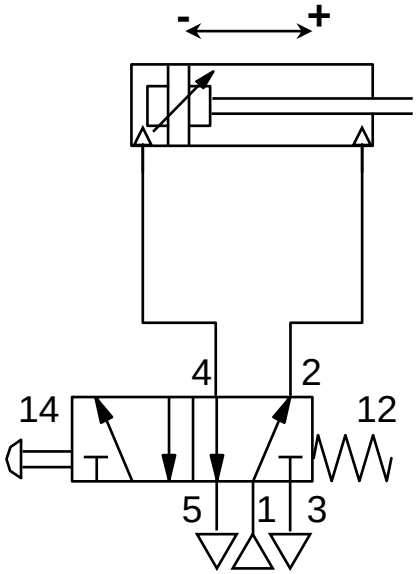


Actuator control 5/2 valve

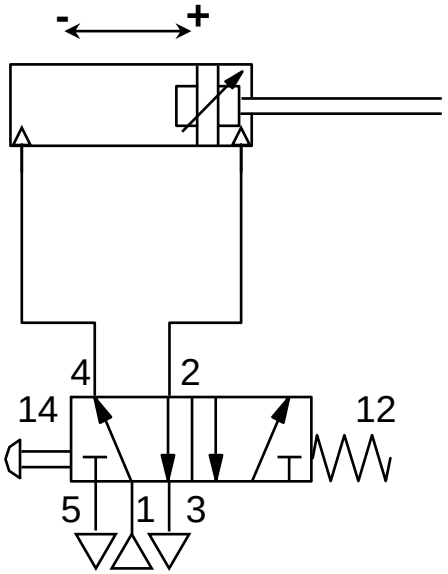
5/2 Valve actuator control

- For a double acting cylinder the power and exhaust paths are switched simultaneously
- When the button is pushed the supply at port 1 is connected to port 4 and the outlet port 2 connected to exhaust port 3. The cylinder moves plus
- When the button is released port 1 is connected to port 2 and port 4 connected to port 5. Cylinder minus



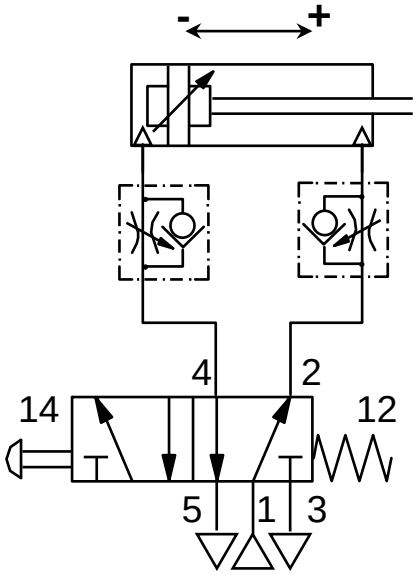
5/2 Valve actuator control

- **For a double acting cylinder the power and exhaust paths are switched simultaneously**
- **When the button is pushed the supply at port 1 is connected to port 4 and the outlet port 2 connected to exhaust port 3. The cylinder moves plus**
- **When the button is released port 1 is connected to port 2 and port 4 connected to port 5. Cylinder minus**



5/2 Valve actuator control

- **Independent speed control of the plus and minus movements**
- **In most applications speed is controlled by restricting air out of a cylinder**
- **Full power is developed to drive the piston with speed controlled by restricting the back pressure**



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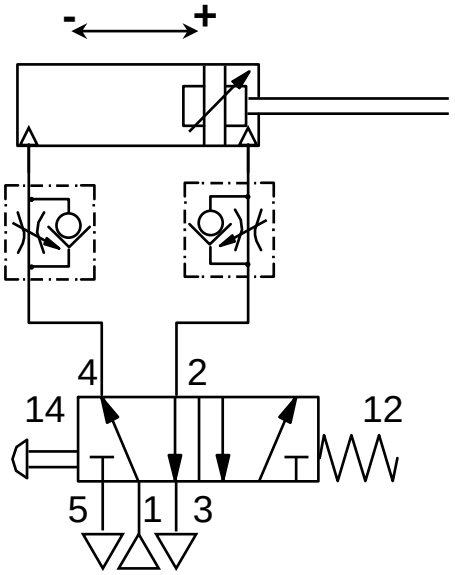
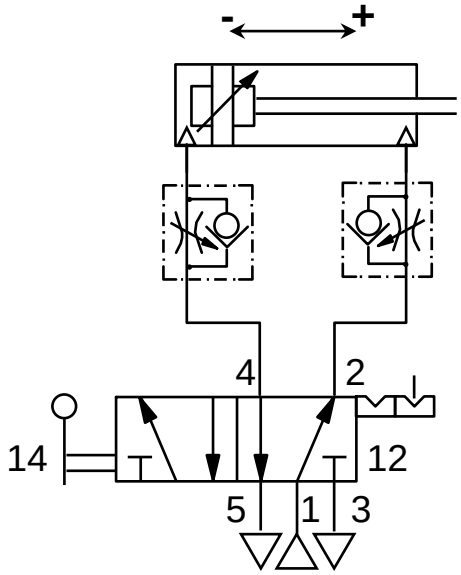


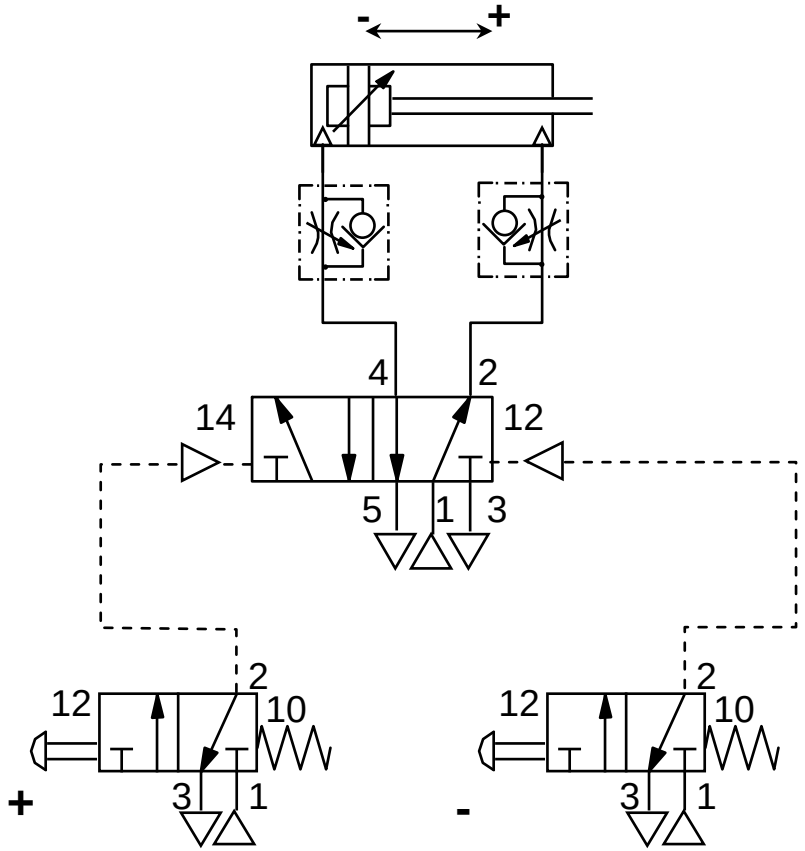
5/2 Valve actuator control

- **Valves with a spring return are mono-stable and need the operator to be held all the time that the cylinder is required in the plus position**
- **Bi-stable valves will stay in the position they were last set**
- **The lever valve example illustrated indicates a detent mechanism. The lever need not be held once the new position has been established**



Manual control

- Remote manual control of a double acting cylinder
- Valve marked + will cause the cylinder to outstroke or move plus
- Valve marked - will cause the cylinder to instroke or move minus
- The 5/2 double pilot valve is bi-stable therefore the push button valves only need to be pulsed



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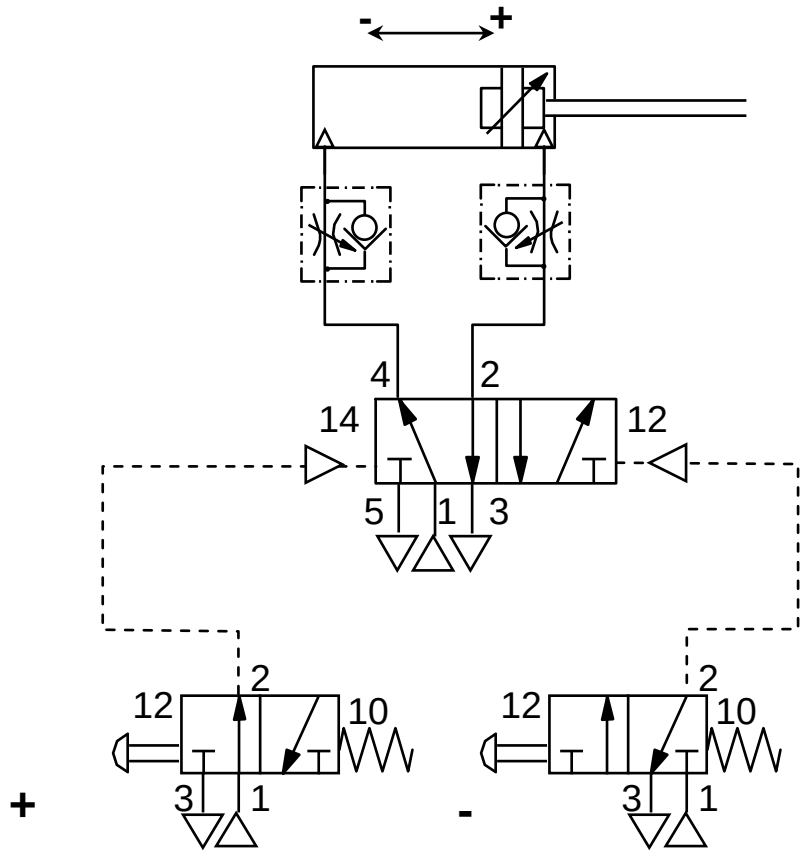

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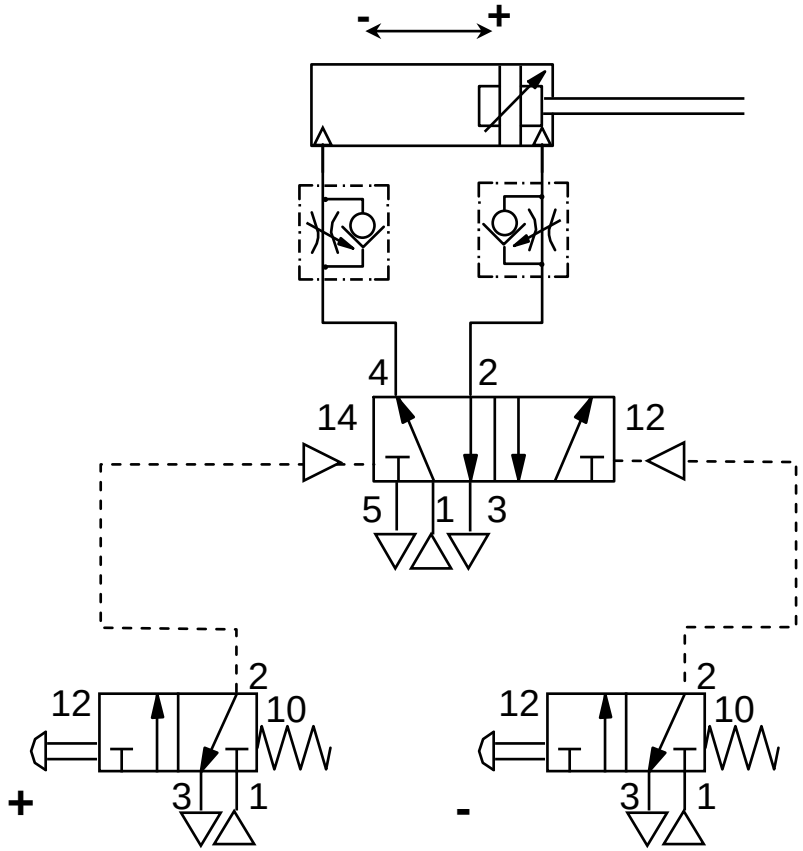

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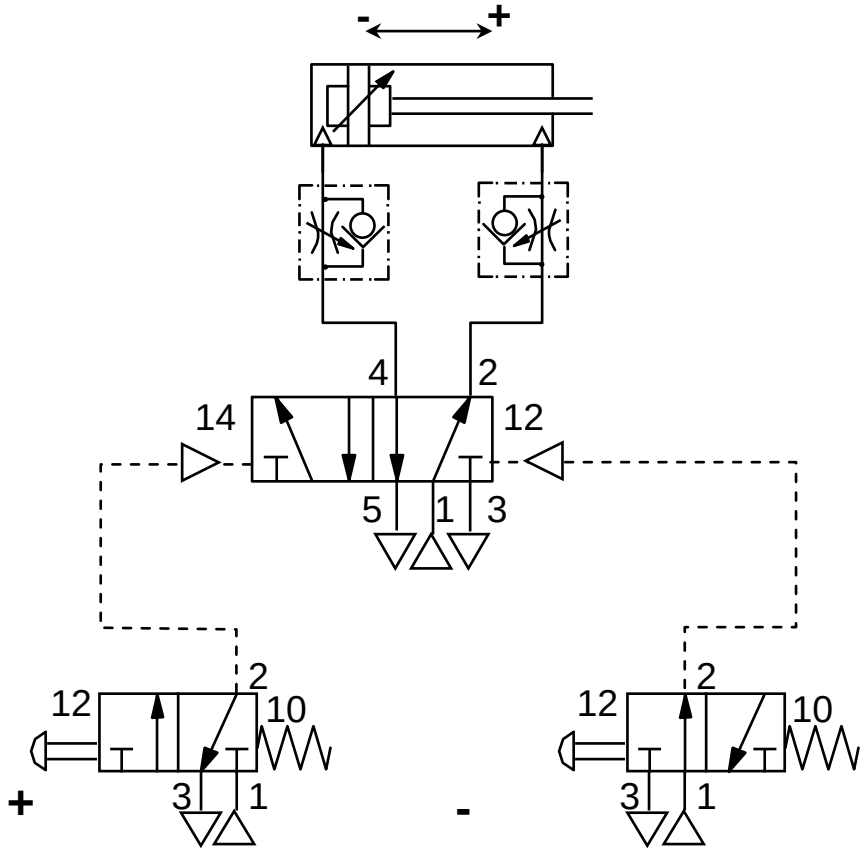

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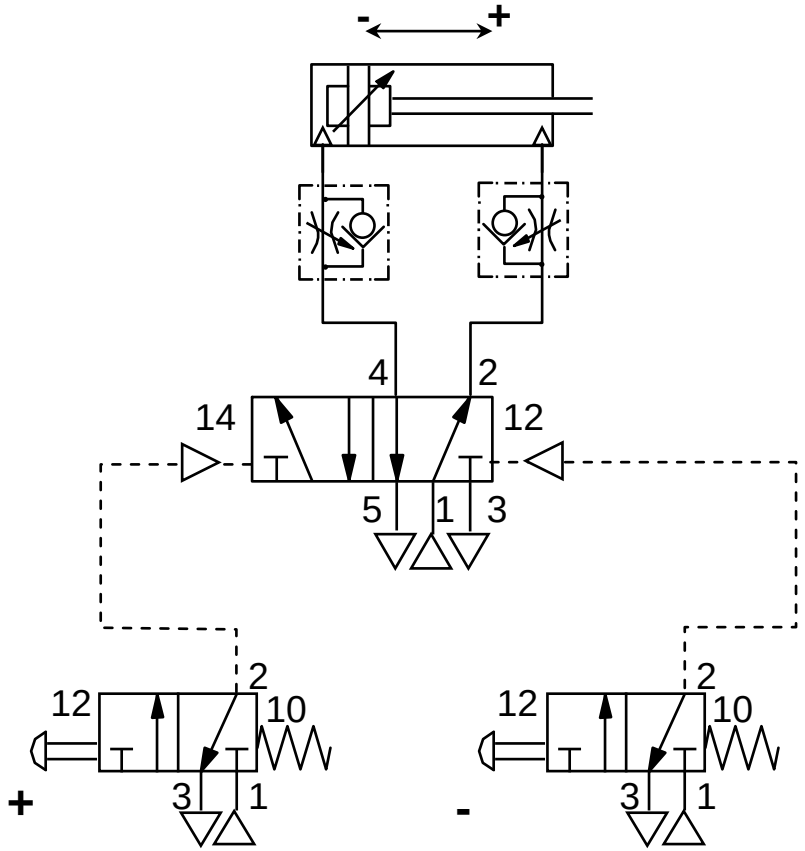
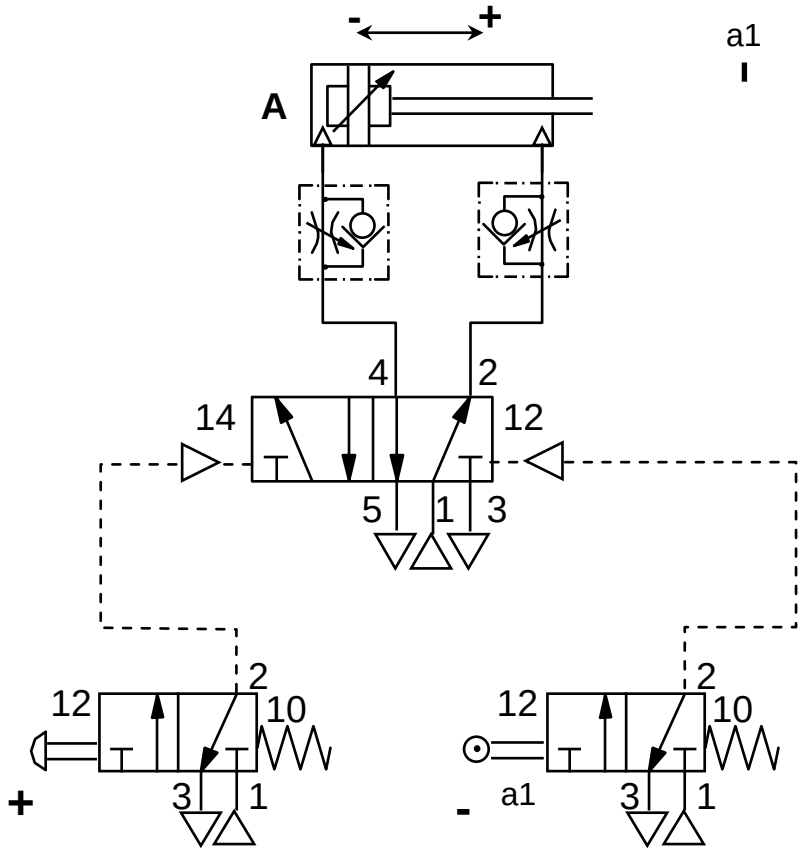
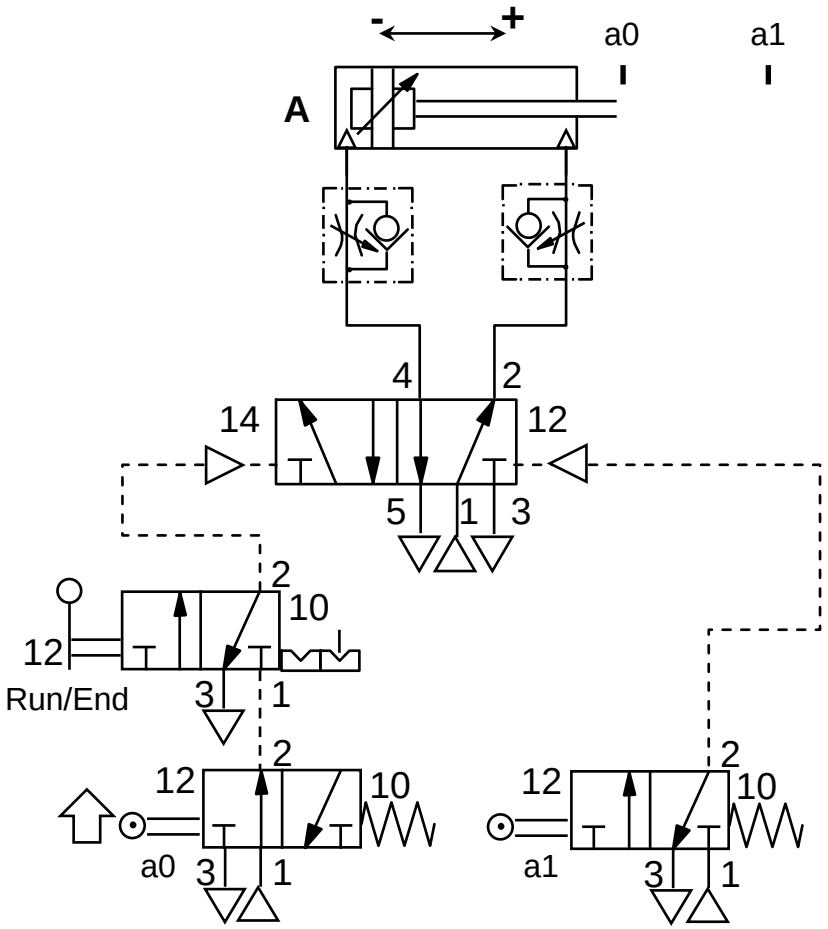


Semi-automatic control

- **Manual remote start of a double acting cylinder with automatic return**
- **Cylinder identified as “A”**
- **Trip valve operated at the completion of the plus stroke identified as “a1”**



Fully-automatic control

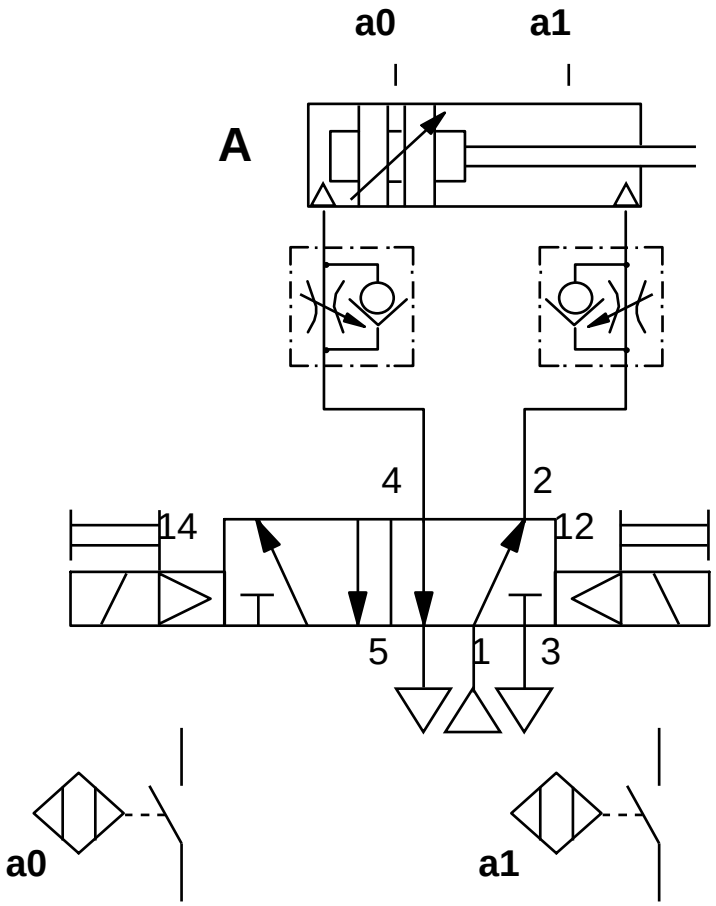


- **Continuous automatic cycling from roller operated trip valves**
- **Manual Run and End of the automatic cycling**
- **Cylinder will come to rest in the instroked position regardless of when the valve is put to End**
- **Tags for the roller feedback valves a0 and a1 show their relative positions**

Electro-pneumatic

- The majority of systems use electrical/electronic control due to the high degree of sophistication and flexibility
- Solenoid valves are used to control cylinders
- Feedback signals are from reed switches, sensors and electrical limit switches
- Logic is hard wired or programmed in to a PLC (programmable logic controller)

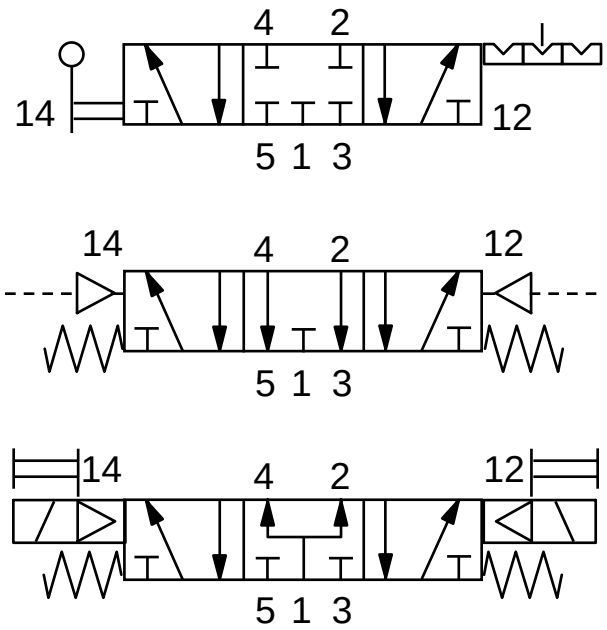
- Circuit building block for each cylinder



5/3 Valve

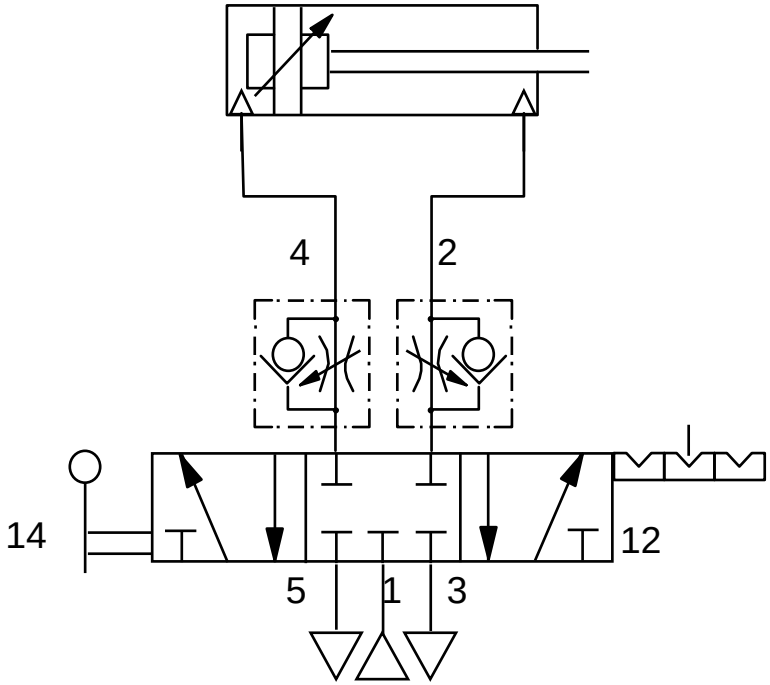
- 5/3 valves have a third mid position
- The valve can be tri-stable e.g. a detented lever operator or mono-stable e.g. a double air or double solenoid with spring centre
- There are three common configurations for the mid position:
  - All ports blocked
  - Centre open exhaust
  - Centre open pressure

- The majority of applications are actuator positioning and safety



5/3 Valve actuator control

- The valve illustrated has “all ports blocked” in the mid position
- Whenever the mid position is selected the pressure conditions in the cylinder will be frozen
- This can be used to stop the piston at part stroke in some positioning applications
- Flow regulators mounted close to the cylinder to minimise creep



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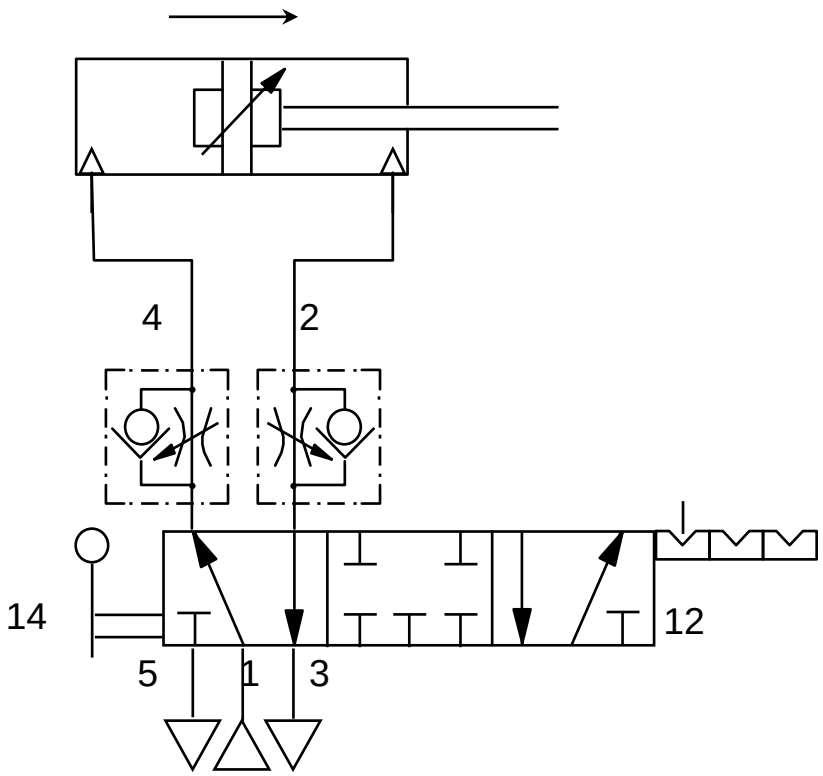

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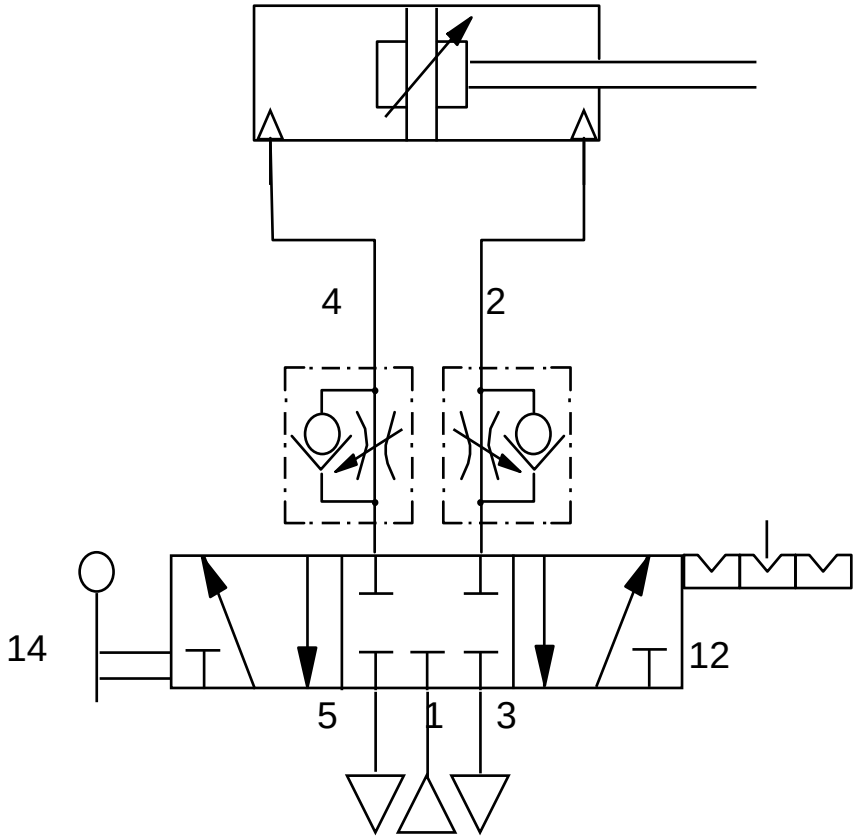

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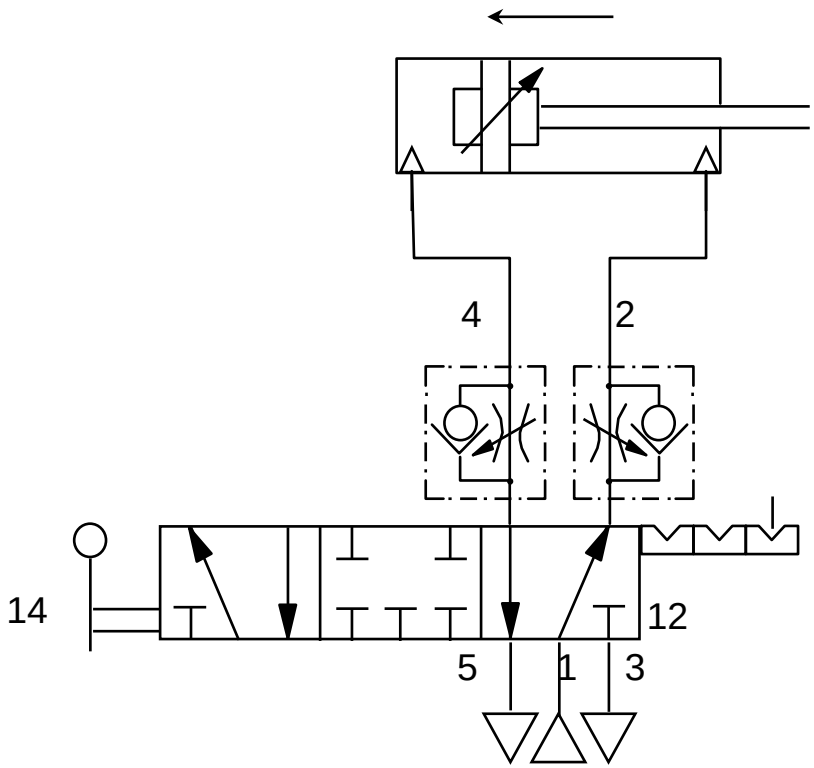

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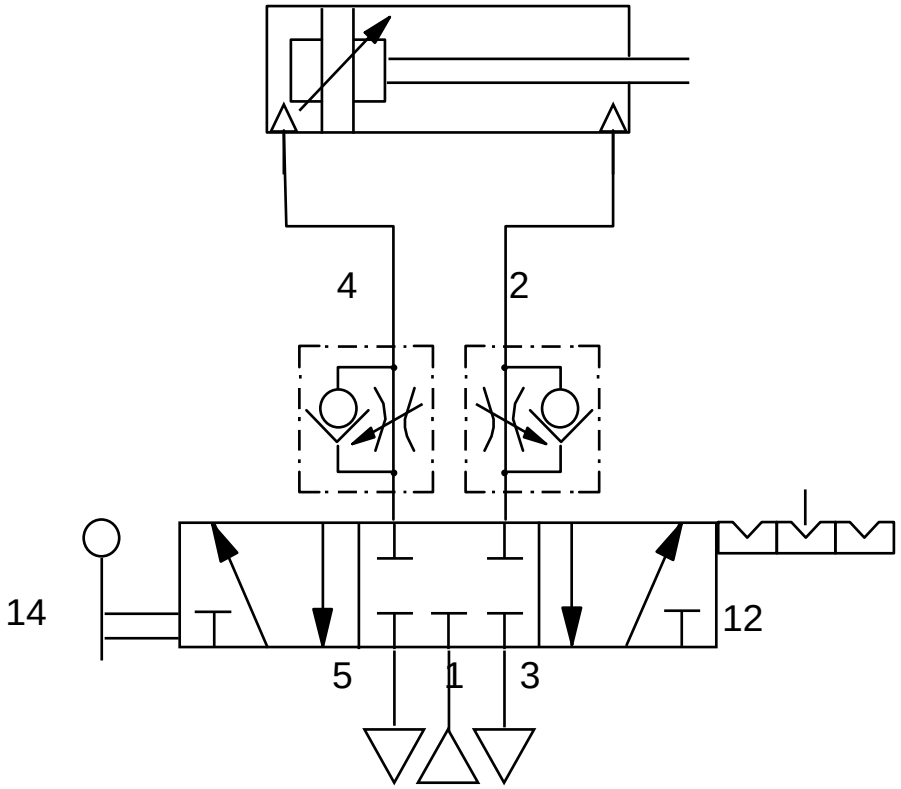
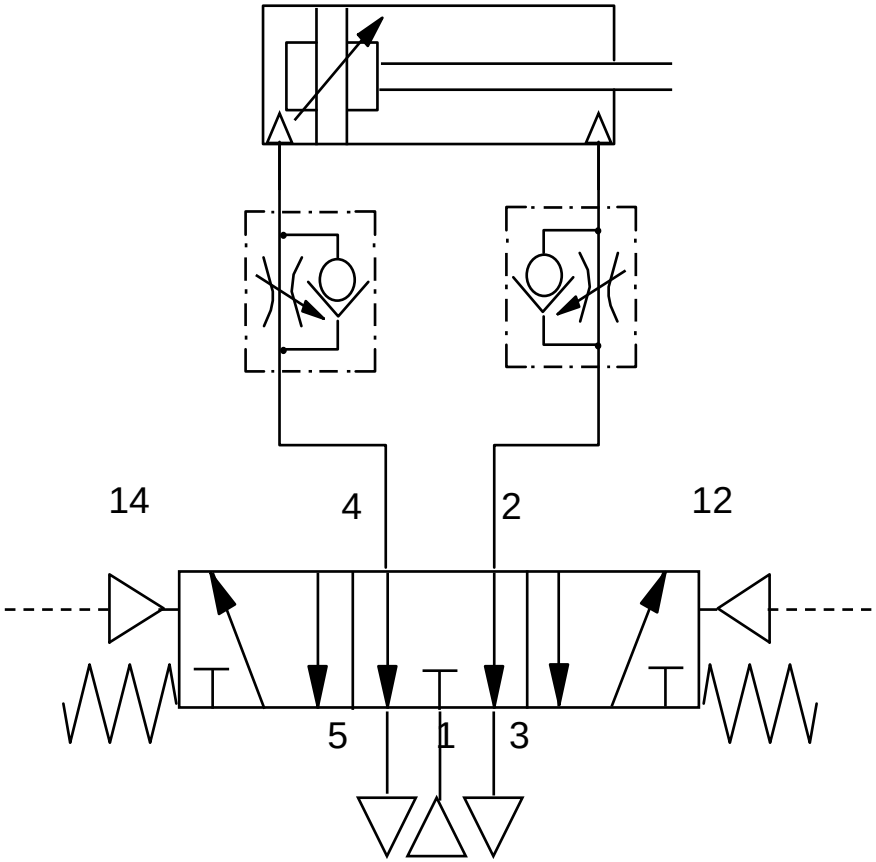


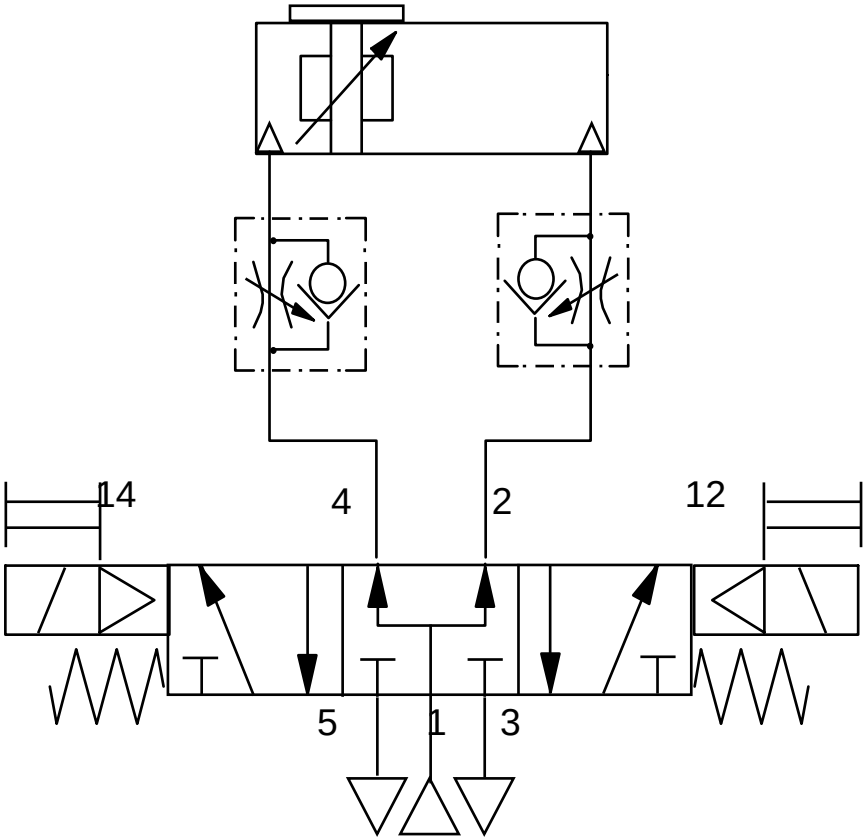
5/3 Valve actuator control

- **This version of a 5/3 valve is “centre open exhaust”**
- **The supply at port 1 is isolated and the cylinder has power exhausted when this centre position is selected**
- **The version illustrated shows a mono-stable version double pilot operated spring centre**
- **The cylinder will be pre-exhausted when changing from the mid position**



5/3 Valve actuator control

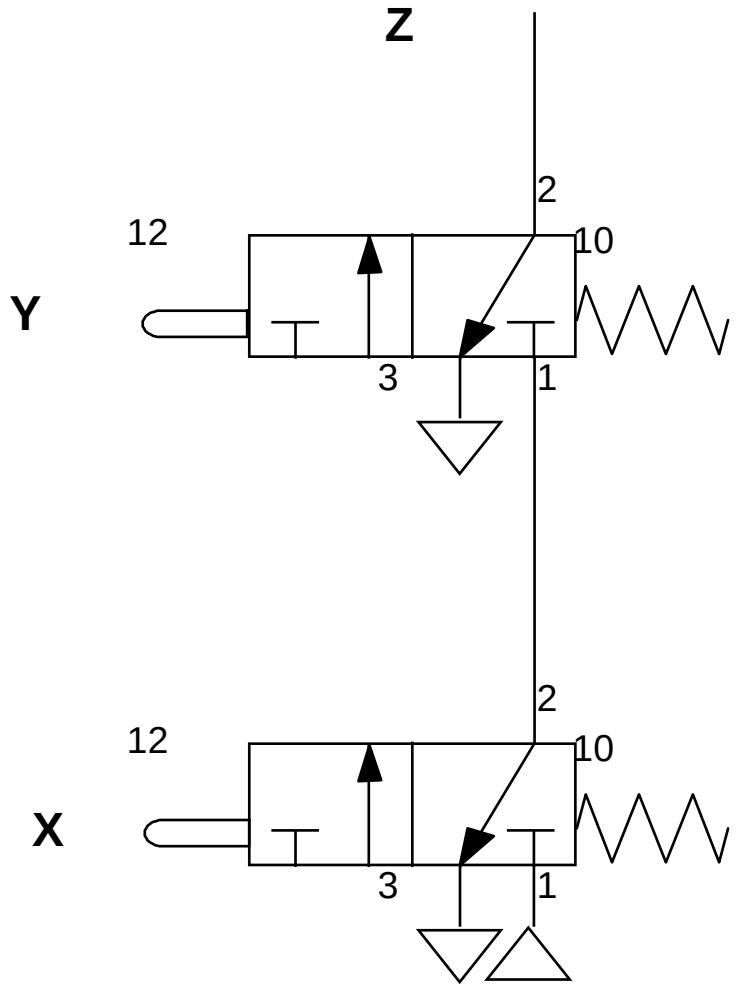
- This version of a 5/3 valve is “centre open pressure”
- The supply at port 1 is connected to both sides of the cylinder and the exhaust ports isolated when this centre position is selected
- Can be used to balance pressures in positioning applications
- The version illustrated is mono-stable, double solenoid, spring centre



Logic functions for valves

Logic AND

- To obtain the output Z both plungers X AND Y must be operated and held
- If X only is operated the air will be blocked at port 1 in valve Y
- If Y only is operated there will be no pressure available at port 1
- If either X or Y is released the output signal Z will be lost



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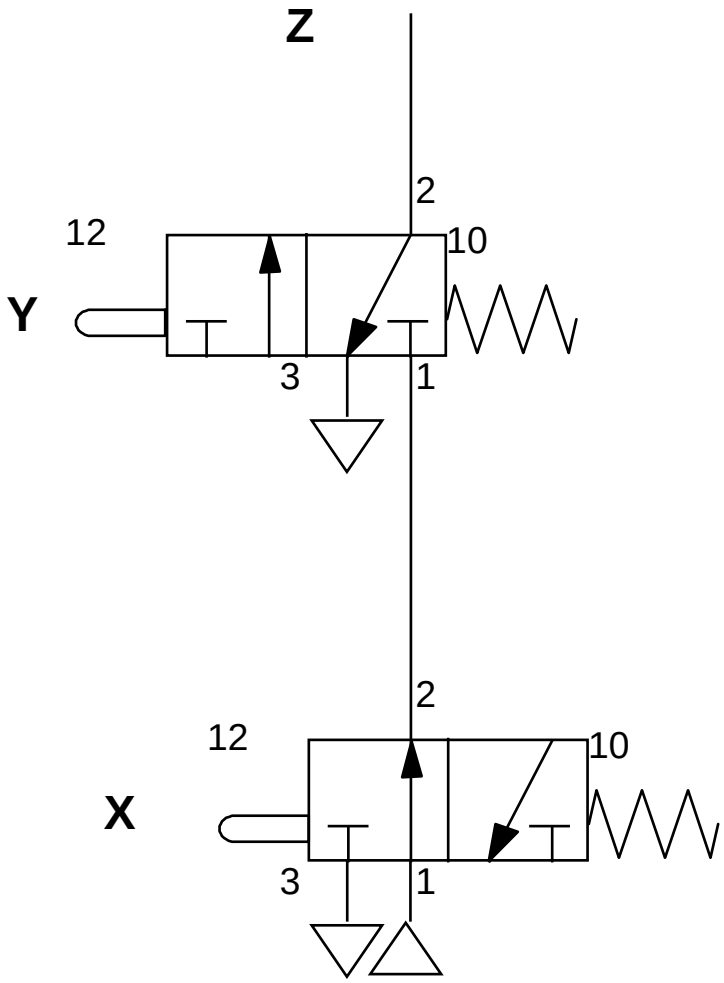

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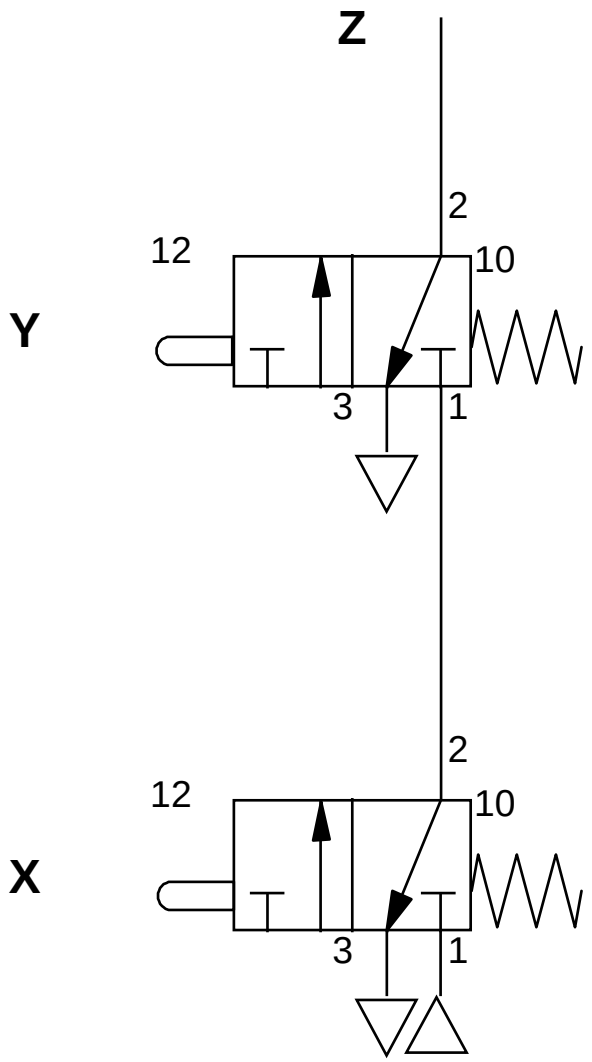

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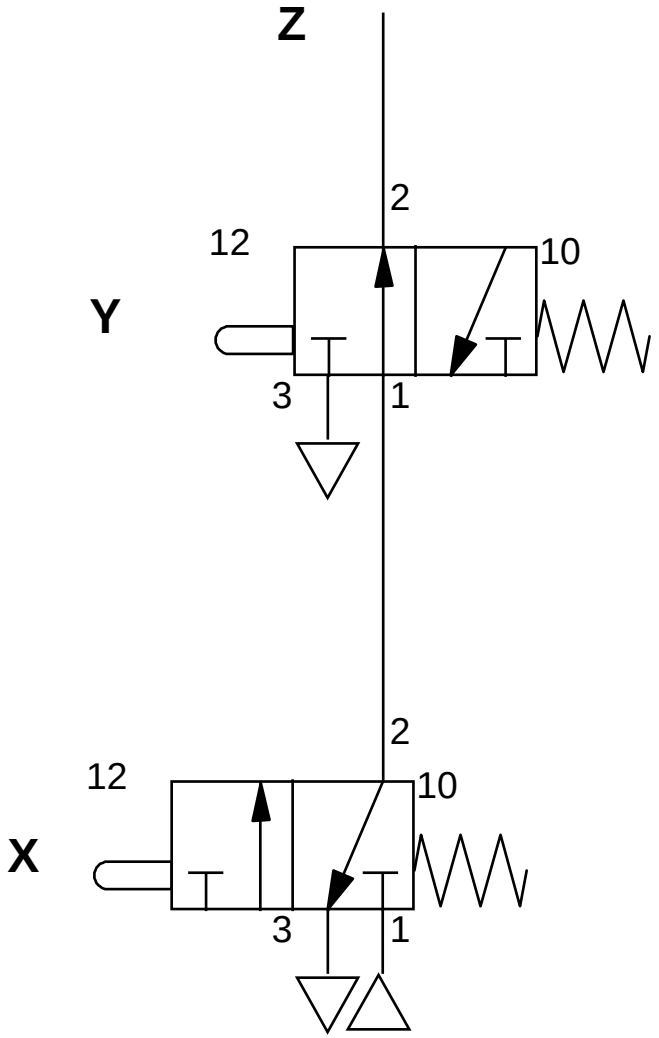

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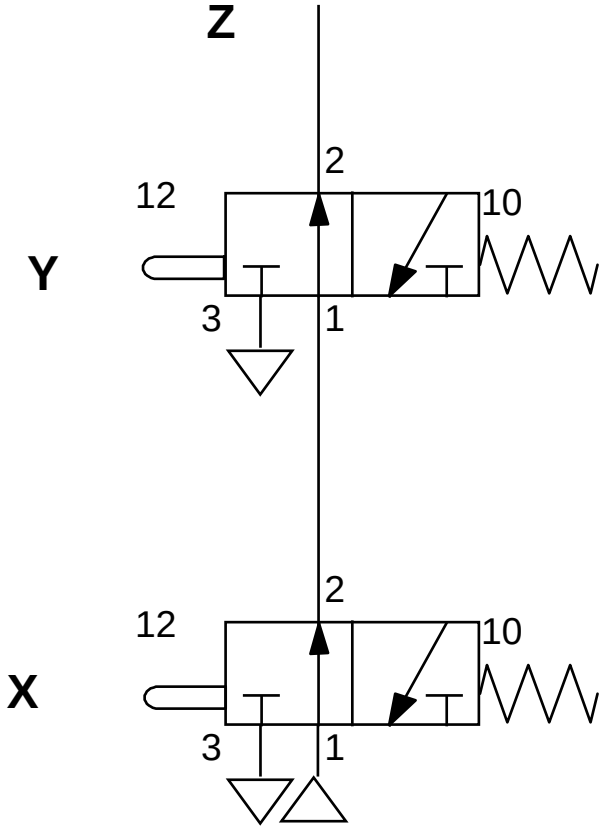

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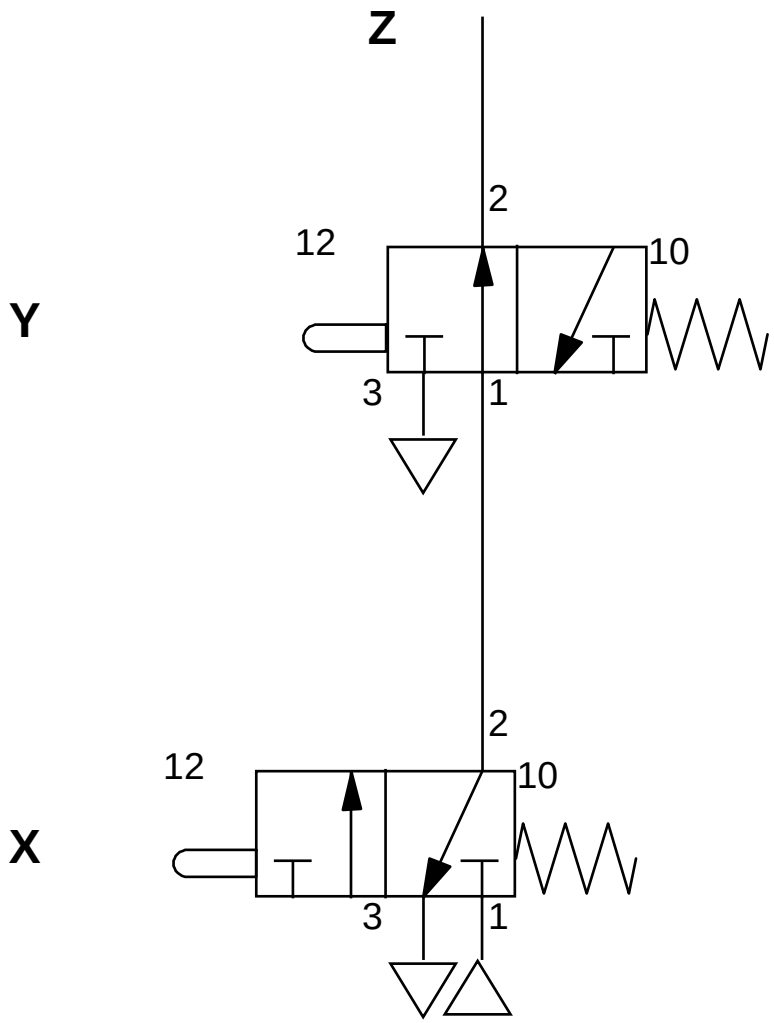

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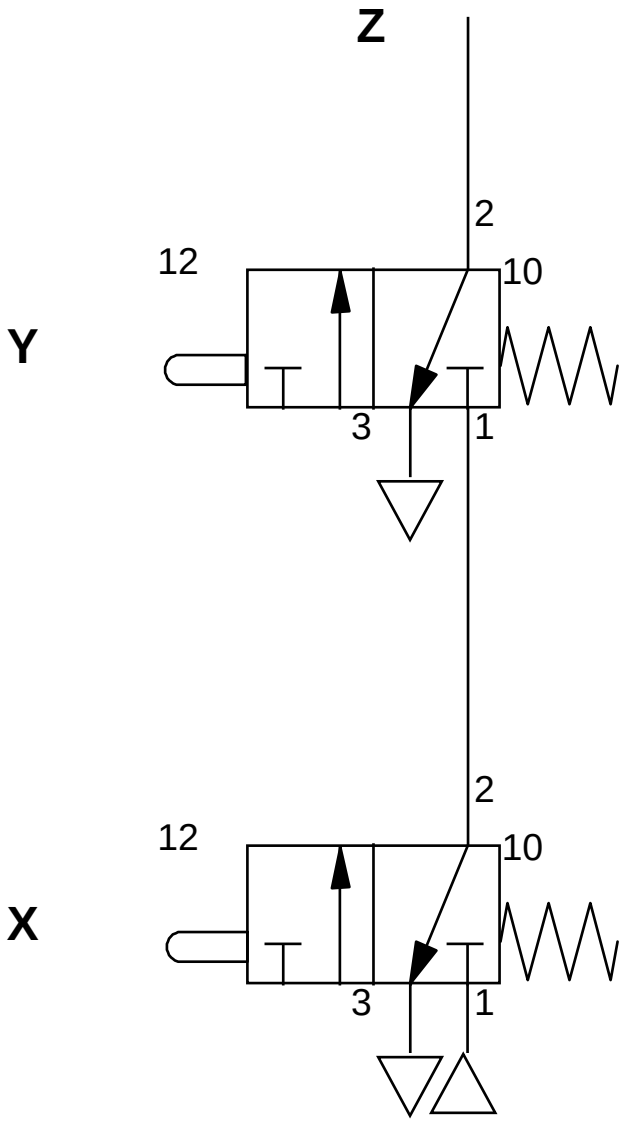
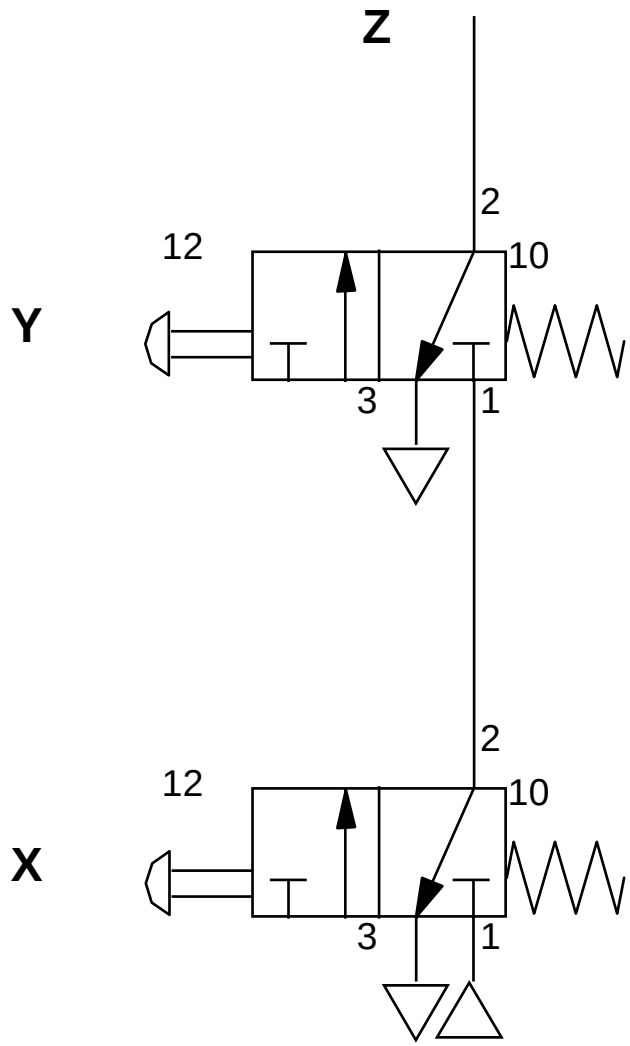


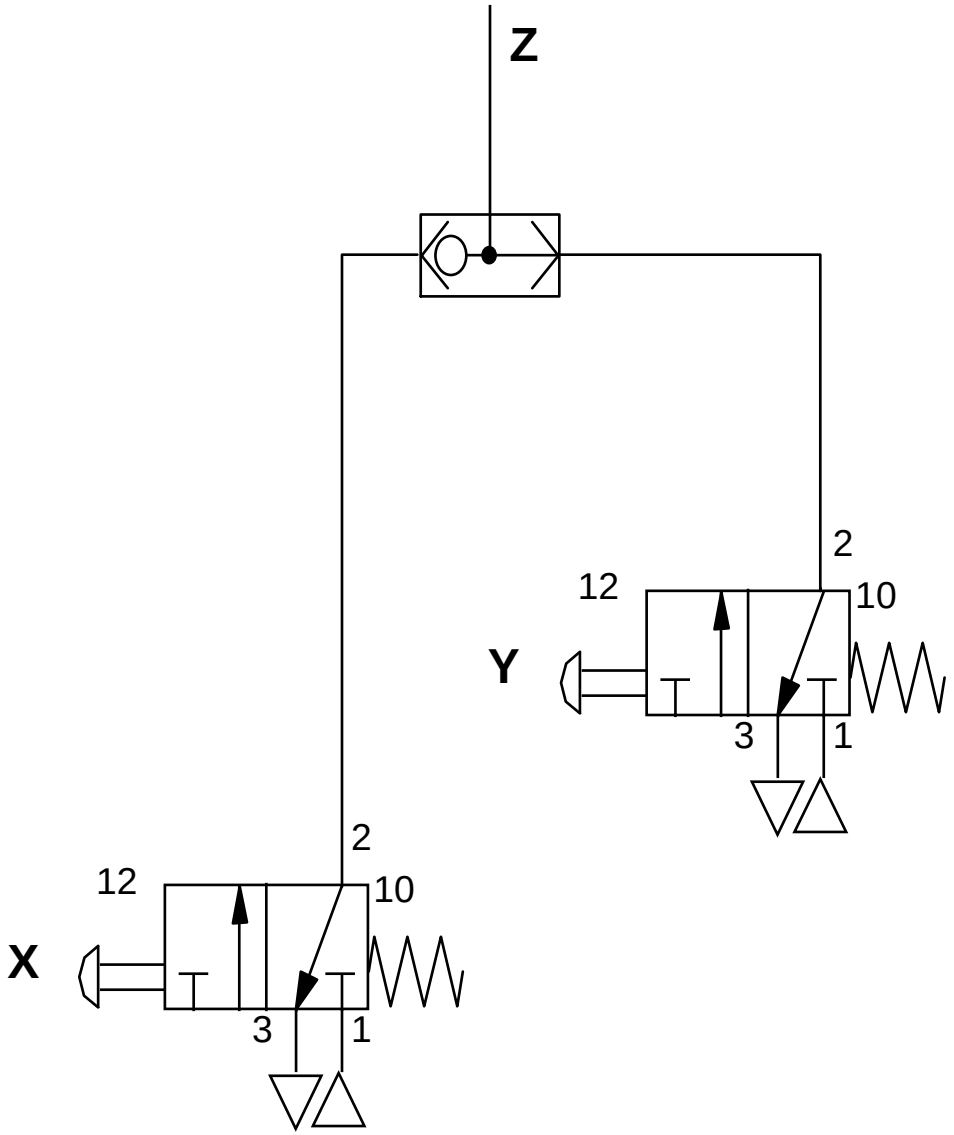
Logic AND

- **This method must not be used as a two handed safety control**
- **It is too easy to abuse. e.g. one of the buttons could be permanently fixed down and the system operated from the other button only**
- **Use the purpose designed two handed safety control unit**



Logic OR

- **Use of an ‘OR’ function shuttle valve**
- **Source X and Y can be remote from each other and remote from the destination of Z**
- **When X or Y is operated the shuttle valve seal moves across to prevent the signal Z from being lost through the exhaust of the other valve**



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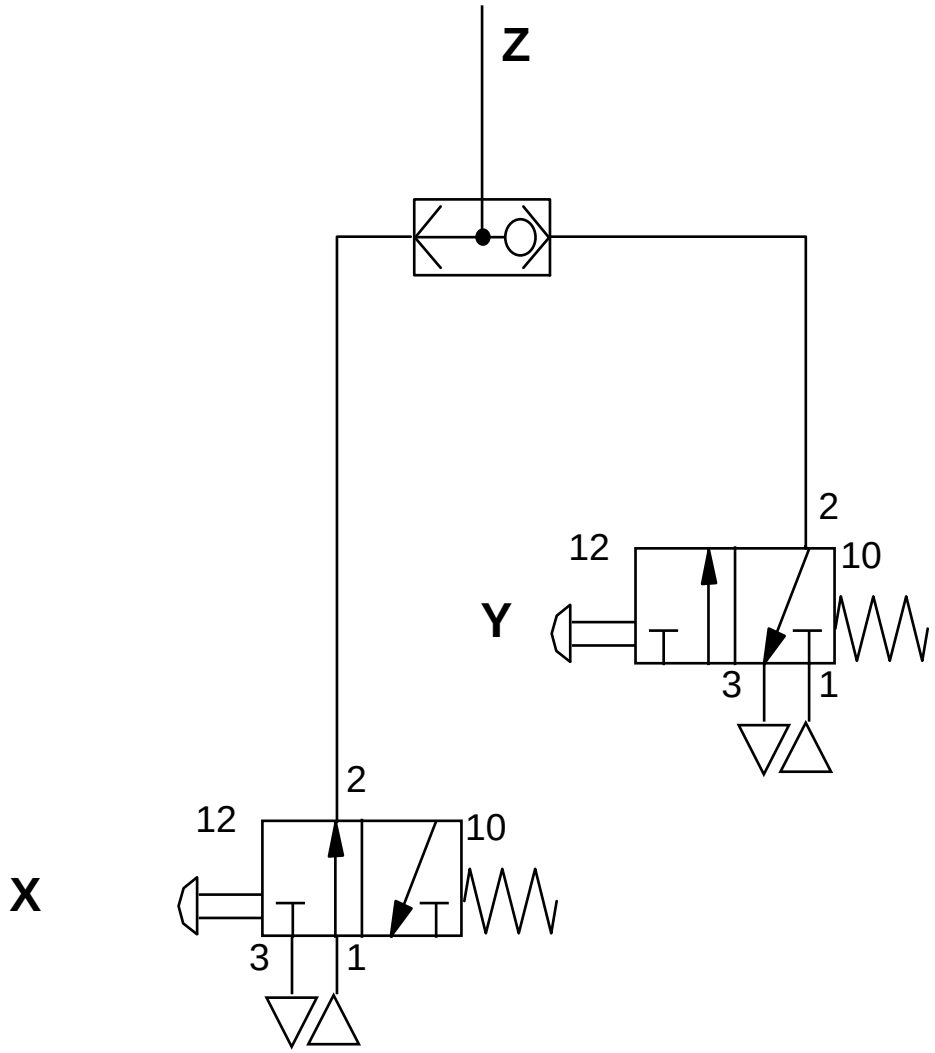

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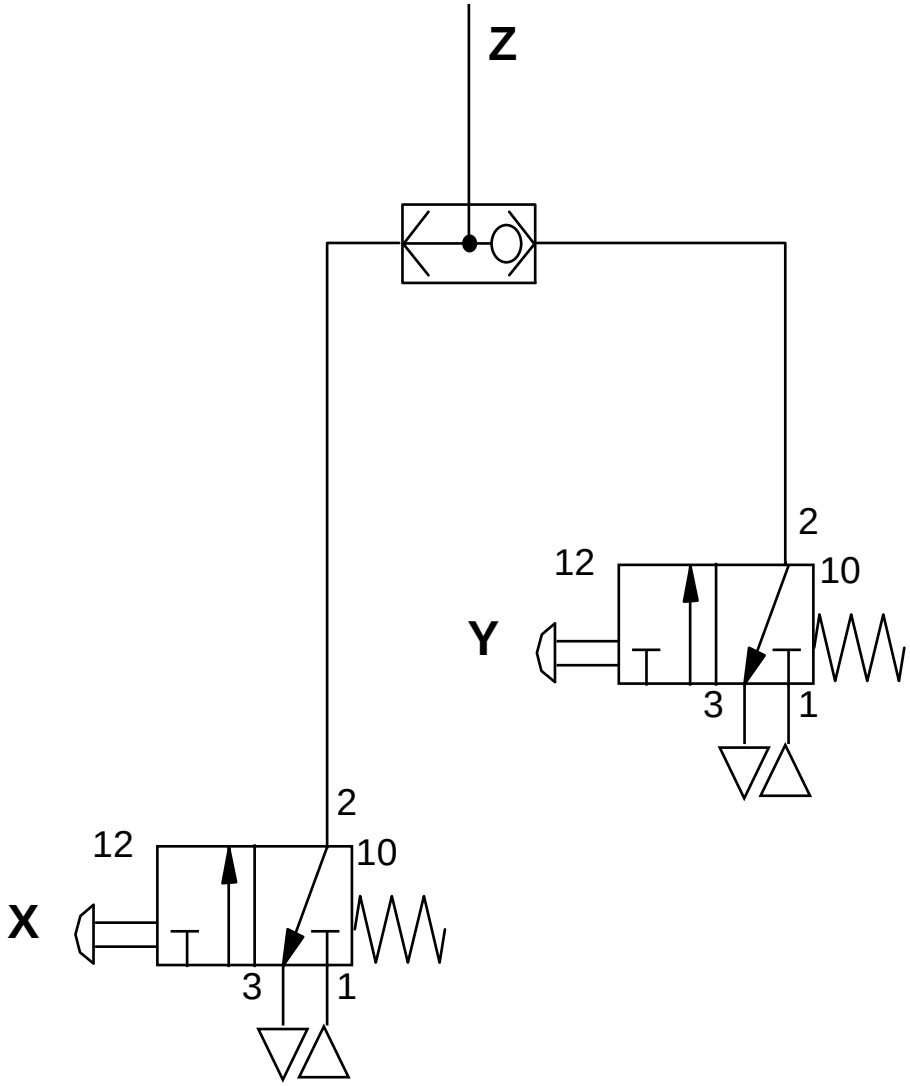

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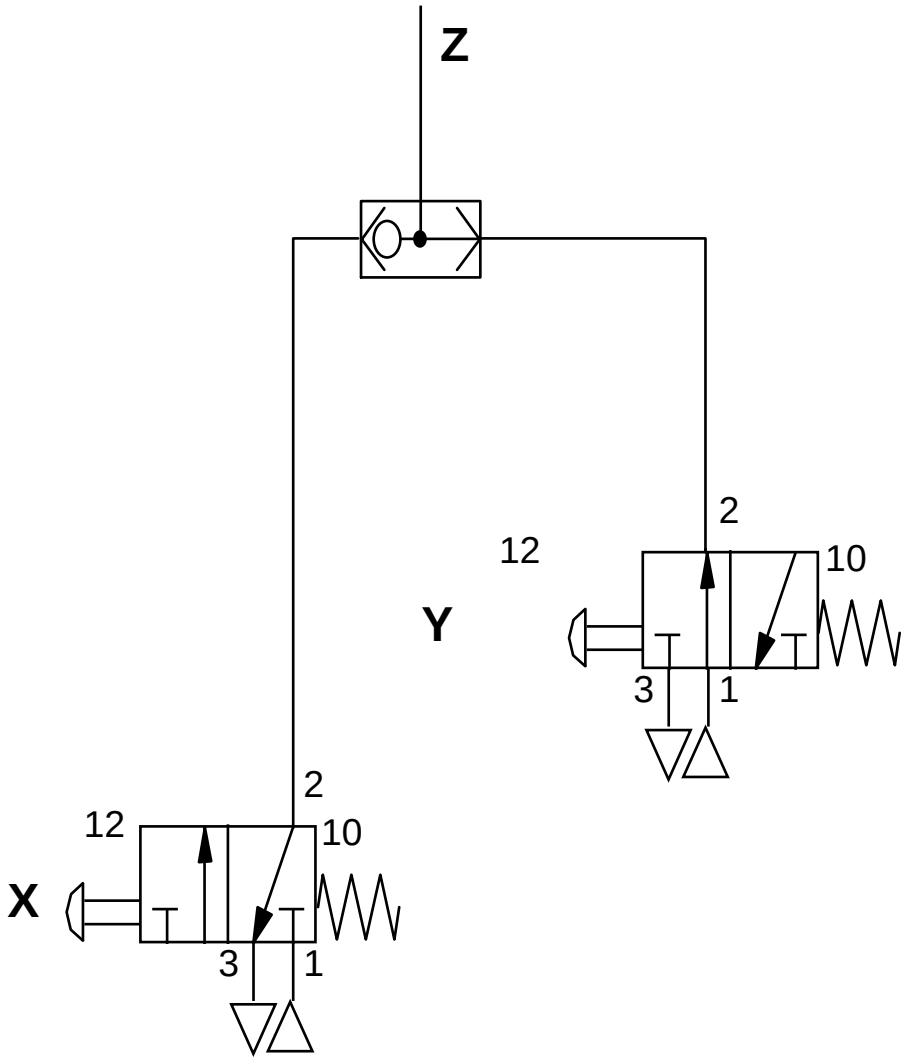

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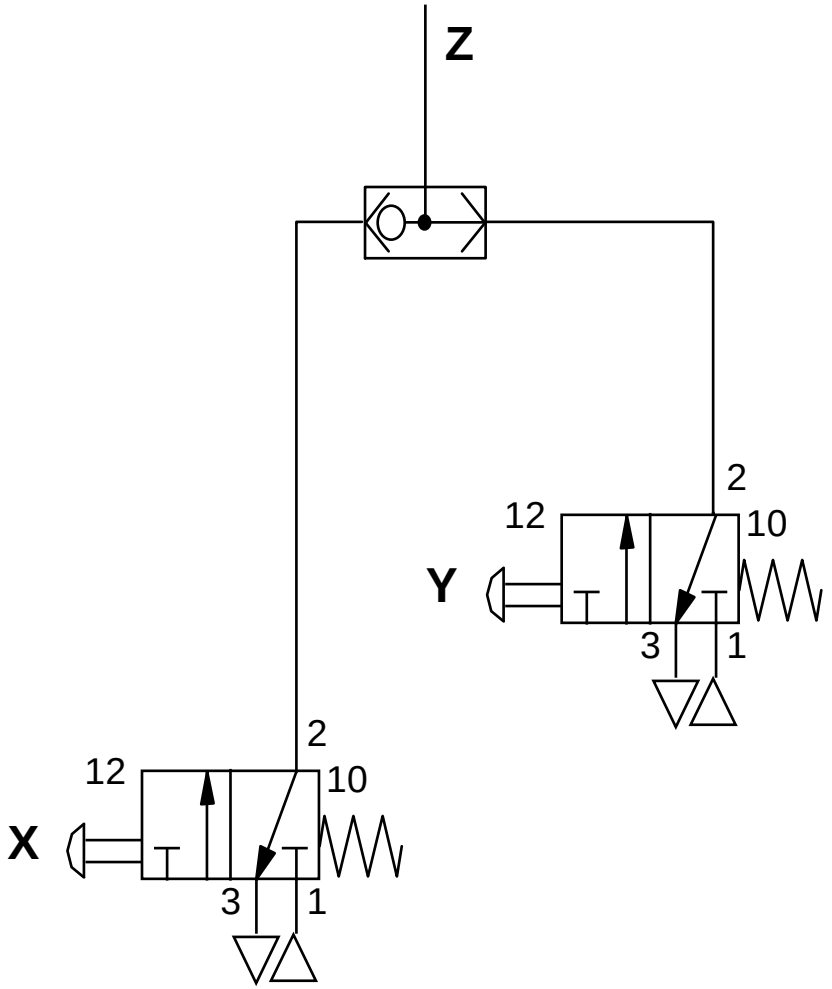
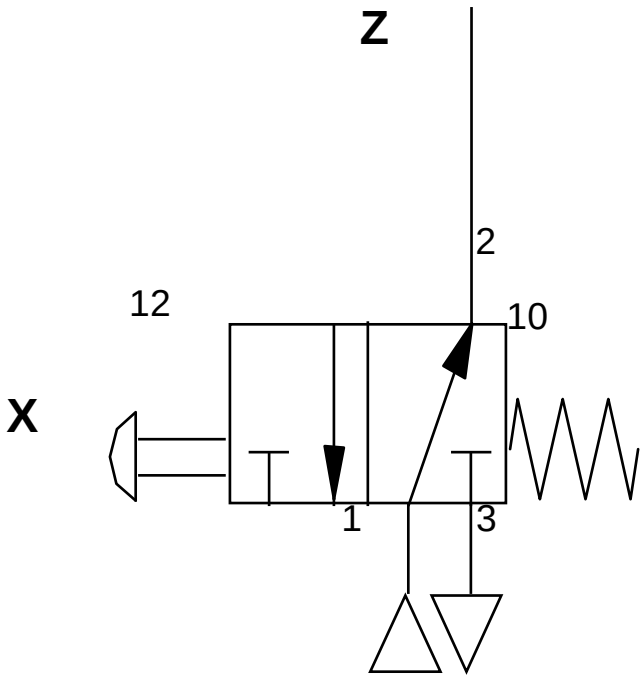


Logic NOT

- A logic NOT applies to the state of the output when the operating signal is present (the output is simply an inversion of the operating signal)
- The valve shown is a normally open type (inlet port numbered 1)
- When the signal X is present there is NOT output Z
- When X is removed output Z is given



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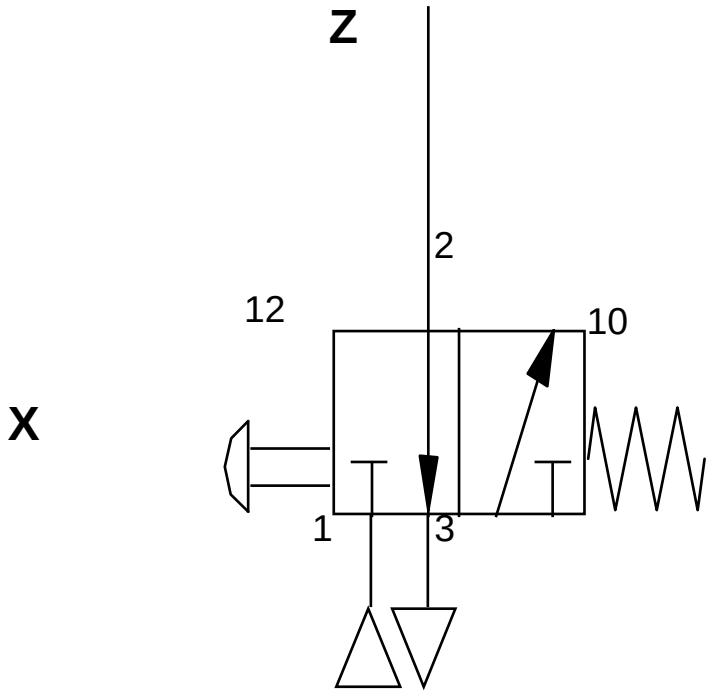

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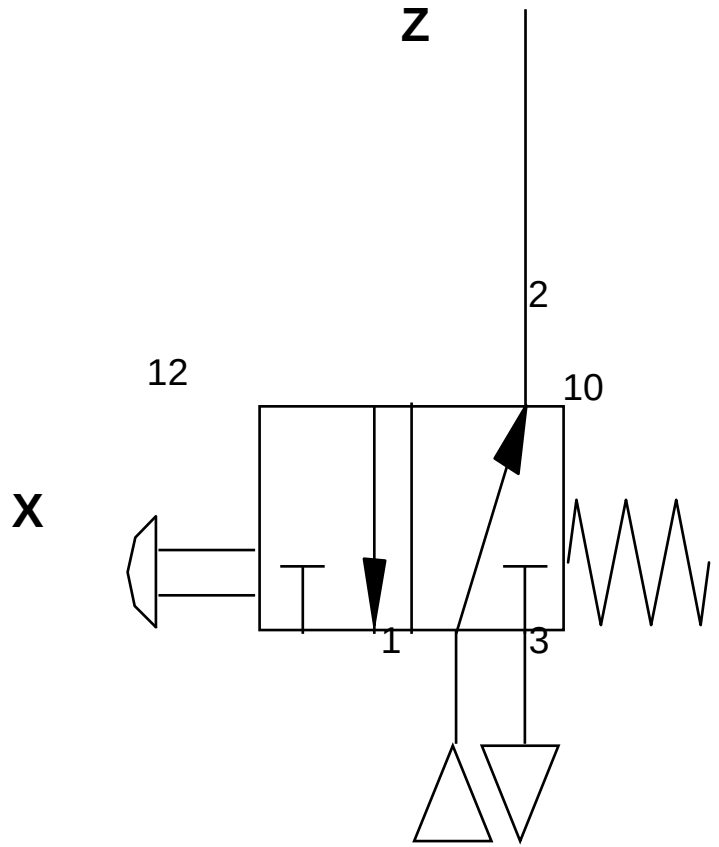
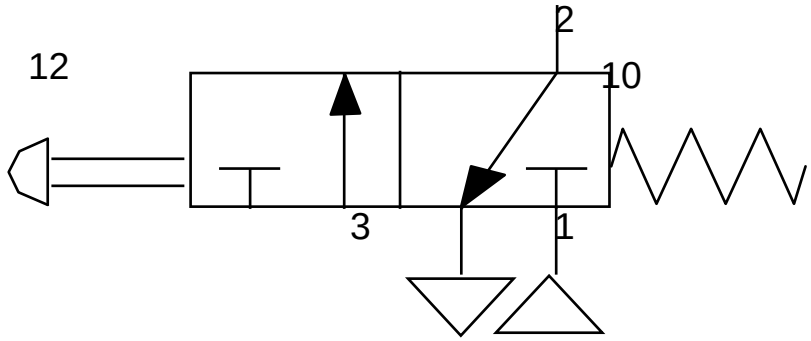
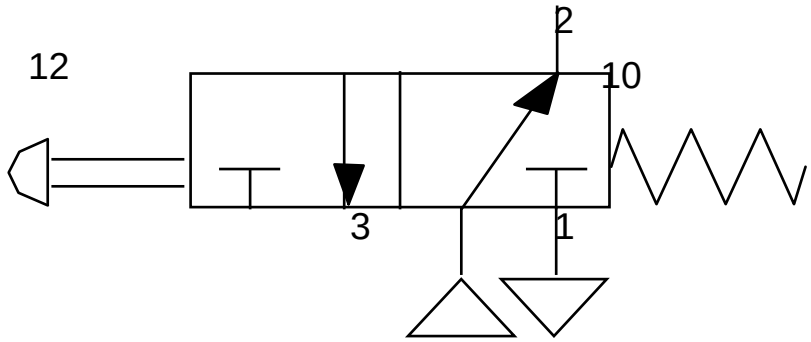


3/2 NO / NC

- **A fully balanced valve allows pressure on any pot or combination of ports**
- **A single valve can be used normally open or normally closed**
- **For normally open the supply pressure is connected to port 1**
- **For normally closed the supply pressure is connected to port 3**





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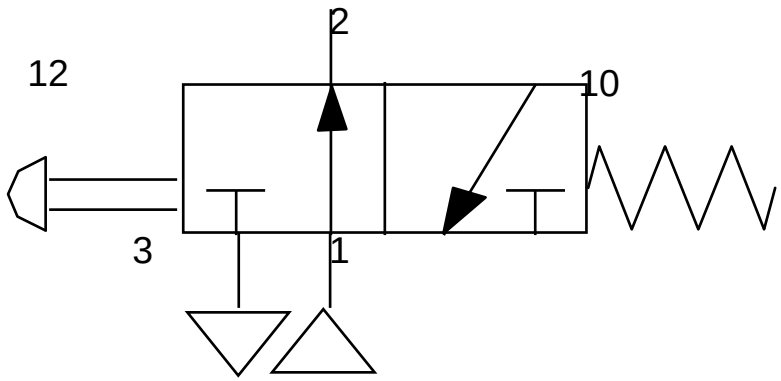
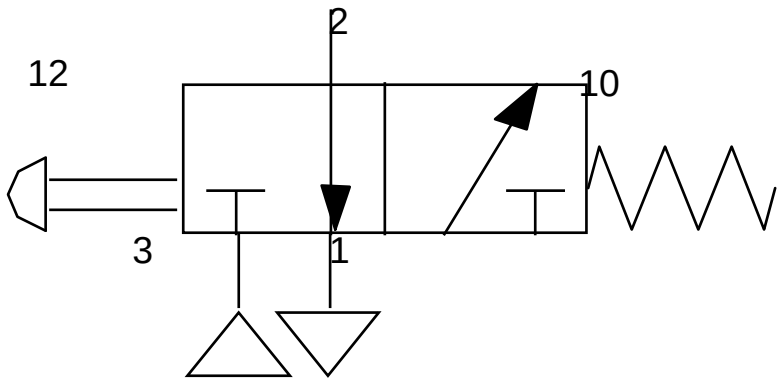
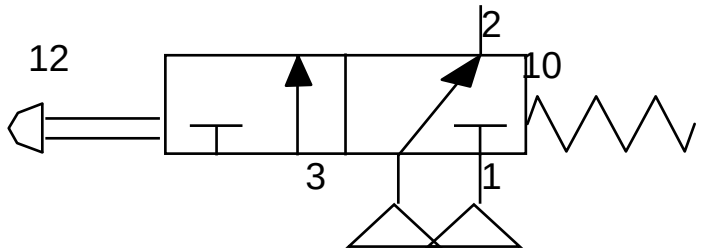
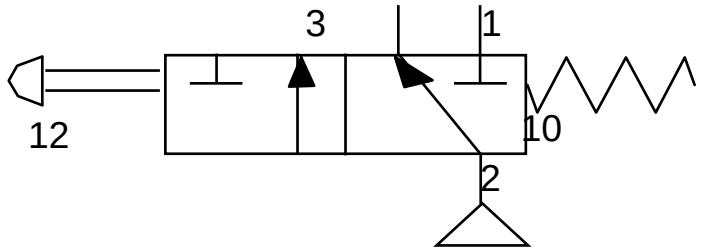




3/2 Valve selection / diversion

- **Selection of one of two supplies connected to ports 1 and 3 can be different pressures**
- **Diversion of one supply to one of two outlets**
- **If it is required to exhaust the downstream air a 5/2 valve is required**





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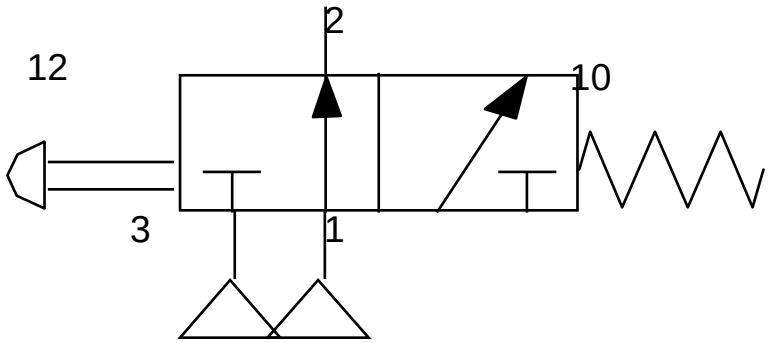
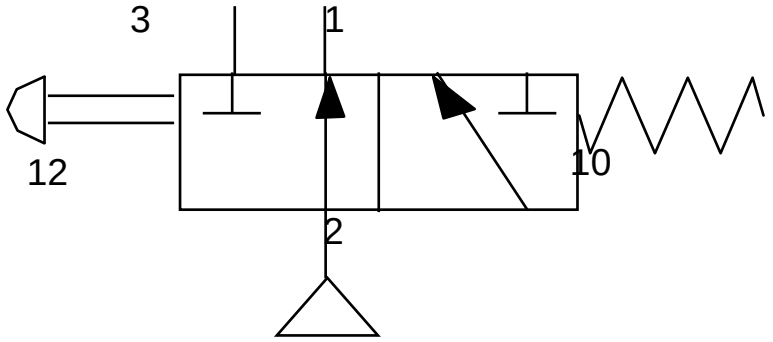
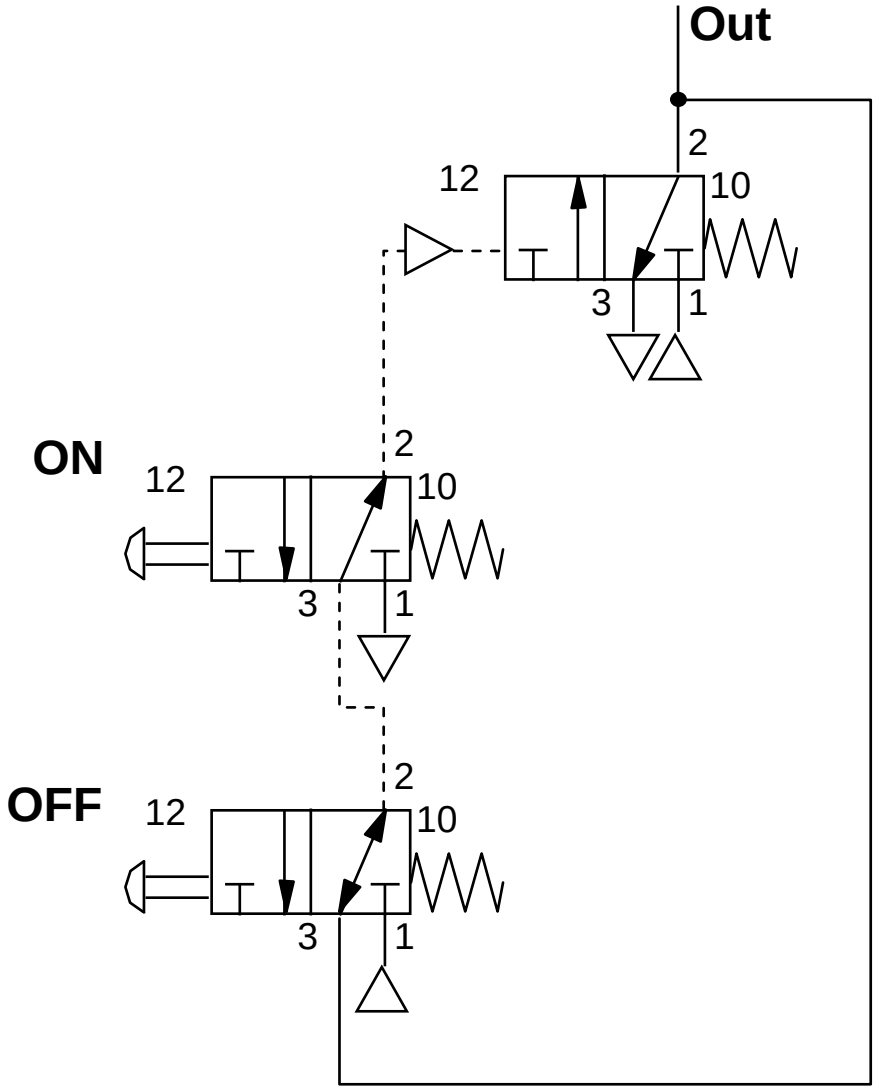




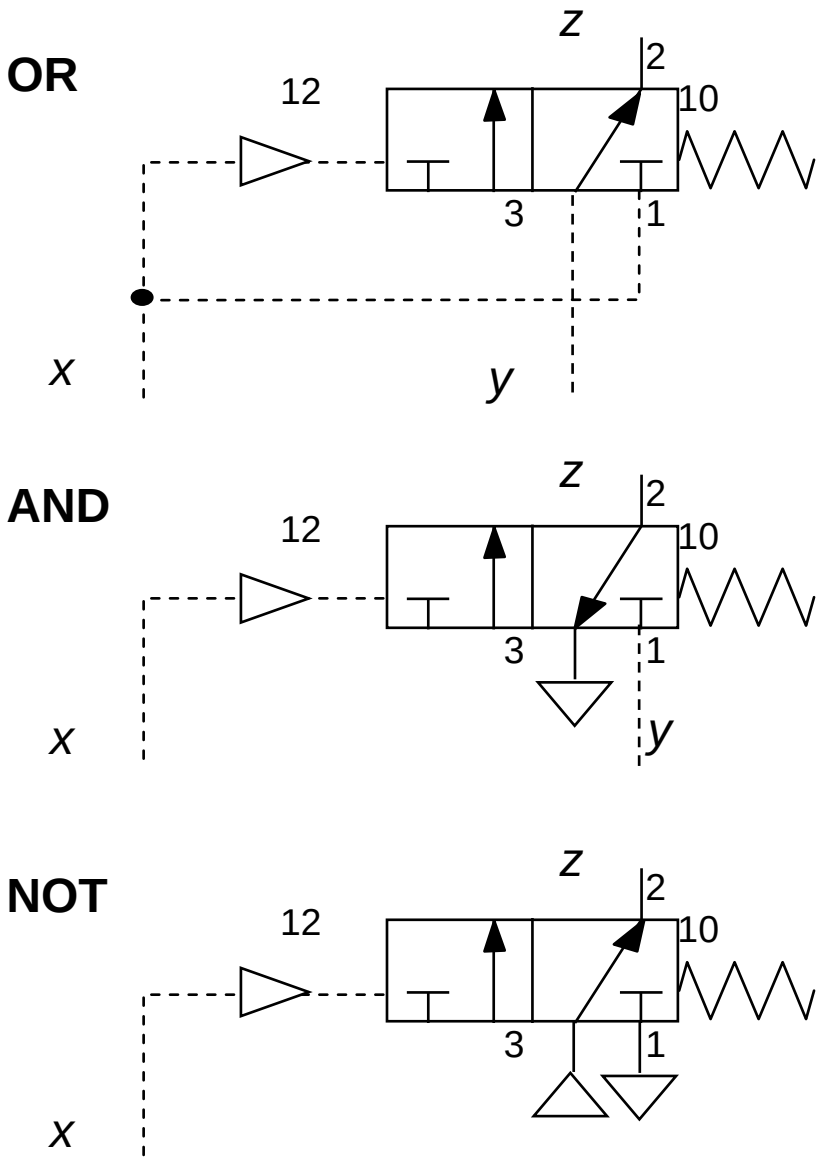
Latch with controls

- In this version of a latch the push button valves are connected to perform ‘OR’ and ‘NOT’ functions
- The ‘OFF’ valve must be placed last in the signal chain so that if both valves are operated together the ‘OFF’ command will dominate over the ‘ON’ command



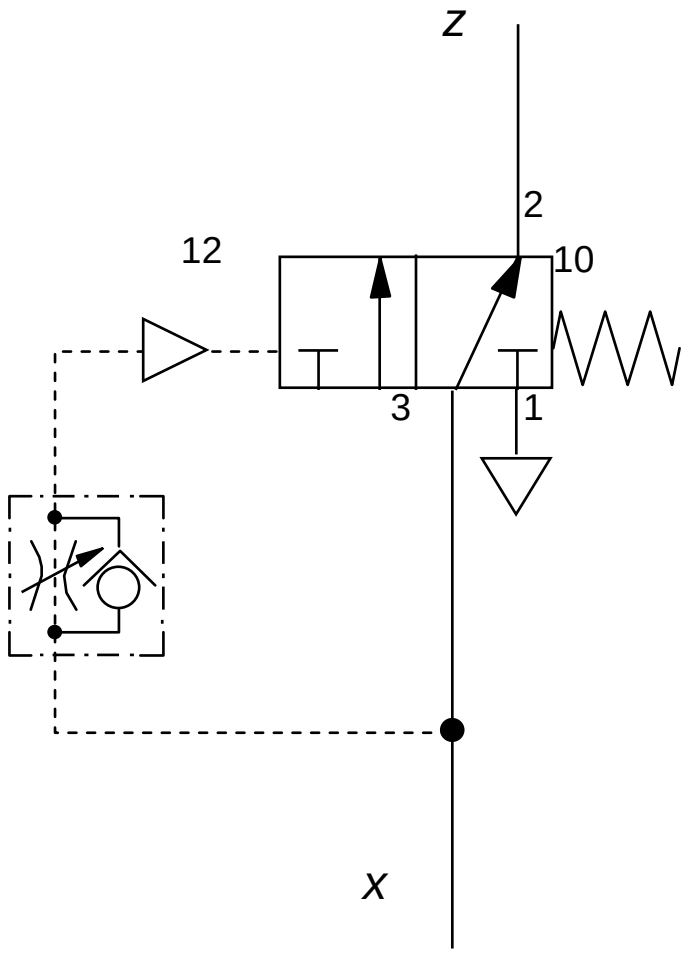
OR, AND, NOT

- **A single 3/2 pilot operated spring return valve can be use for any of these logic functions**
- ***x* OR *y* gives output *z***
- ***x* AND *y* gives output *z***
- ***x* gives NOT *z***



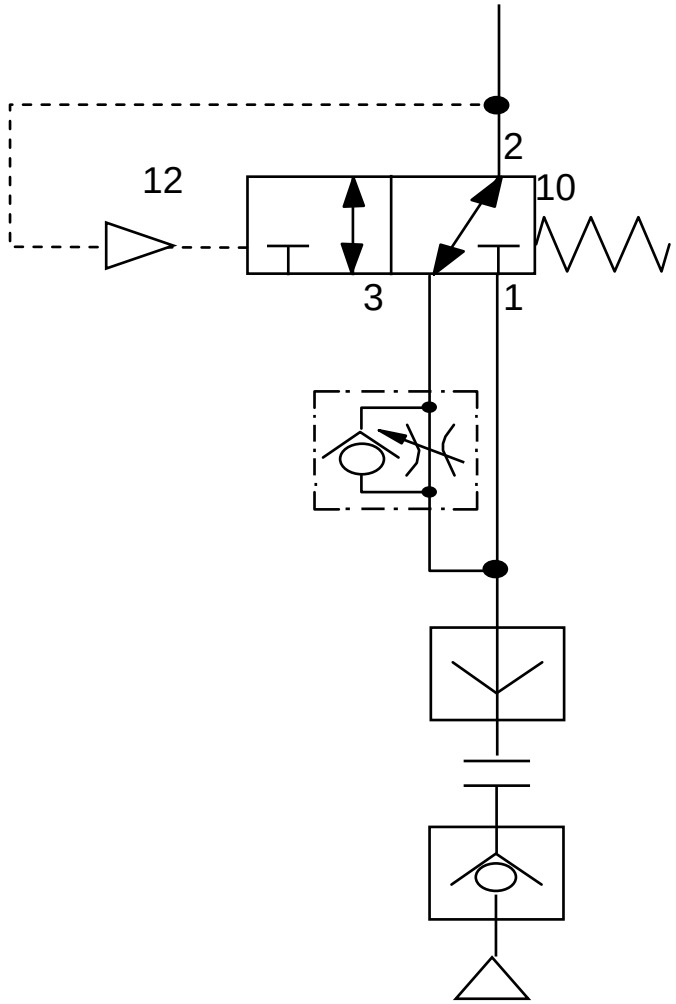
Single pulse maker

- **Converts a prolonged signal *x* into a single pulse *z***
- **Signal z must be removed to allow the valve to reset then x can be applied again**
- **The duration of the pulse can be adjusted with the flow regulator**



Slow initial pressure build up

- **Choose a 3/2 pilot spring valve with a relatively high operating force e.g. 3 to 4 bar**
- **When the quick connect coupling is made, the output at port 2 is controlled at the rate of the flow regulator setting**
- **When the pressure is high enough to operate the valve full flow will take over**



End