MEC-E5003 Fluid Power Basics

Brief history of pneumatics

Compressed air is used widely in industry in different applications like automation, pneumatic tools, material handling, process industry applications and vacuum technology.
According to various references in western European countries 7-11 % of electric energy used in in industry is used for making compressed air. Compressed air is also the most expensive energy form used by industry.

Some development phases of pneumatics:

1. Compressed air supply network in Paris at 1880's. Pneumatic energy network was designed to work like an energy source just like electric network later on.
2. Pneumatic braking system in 1920. Manually operated braking system with a valve and cylinder.
3. Industrial automation in 1945. Production was boosted with semi and later full automatic systems.
4. Fluidistor technology in 1960's. Fluidistors are pneumatic logic elements that were used for analog logic circuits. Even fully operating computers were built with fluidistors.
5. Electric control of pneumatics 1970 and later. Programmable logics and later (1990's) bus interfaces were developed to control pneumatic valves and systems.

Where to use pneumatics today

Pneumatic systems are competing all the time with electric controls and actuators. Maybe half of machine automation pneumatics are in machines that are used for material handling and packaging.
In machine automation pneumatics is used especially when:

- light weight pieces are handled
- fast linear movements are required
- movements are from end position to the other end position of the actuator
- soft gripping and movements are required
- hygienic systems are required
- operation is located in a fire or explosion sensitive place
- pneumatic power tools are used.

Characteristics of pneumatics:

+ advantages

1. unlimited source of pressure media
2. easy to storage even for hours or a couple of days
3. easy to transfer pneumatic energy even long ways
4. cleanliness of the technology
5. reserve energy from the reservoir when there is an electric breakage
6. pneumatics is safe to use in explosion sensitive places
7. natural overloading protection
8. easy and simple ways to control speed and force
9. simple and inexpensive components
10. high speeds (cylinder piston speed max 10-20 m/s, motor rotating speed varies between 10 - 500.000 rpm)

- drawbacks

1. slow and even motion is difficult to achieve (compressibility, friction)
2. small forces compared to hydraulics (cylinder force max about 10 kN)
3. noise level is sometimes high, especially from exhaust air
4. pneumatic control signal speed only about 15 m/s
5. energy consumption of especially pneumatic motors is bad
6. low overall efficiency

Pressures

$p = F/A$ [N/m^2]

N/m^2 = Pascal = Pa

In pneumatic systems pressures are typically between:

300 – 1000 kPa (= 3 – 10 bar)

In hydraulics pressures are typically between:

5 – 45 MPa (= 50 – 450 bar)

In USA the unit for pressure still used is:

1 psi = 1 lbf/in^2 = 6894,8 Pa

absolute pressure = air pressure + over pressure (= ”working pressure”)

absolute underpressure (negative pressure) = air pressure – negative pressure

Compressor types

Compressor types and their typical properties:

a) piston compressors
pressure range: 1 – 1000 bar
flow: 150 – 25000 Nm^3/h (= normal cubic meters per hour (normal means that the volume is converted into atmospheric pressure))

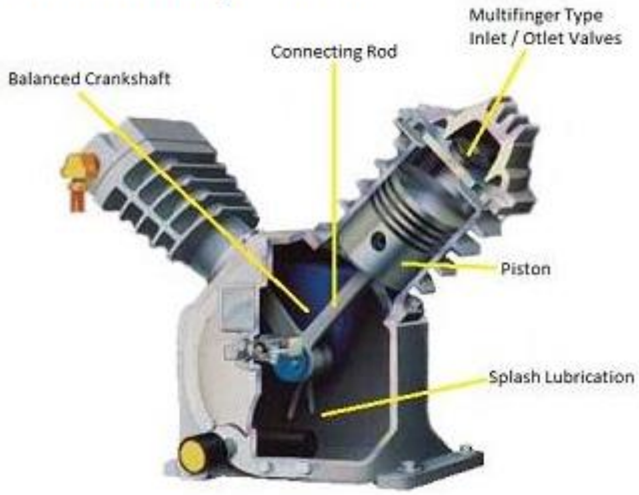
b) screw compressors
pressure range: 0,8 – 25 bar
flow: 800 – 60000 Nm^3/h

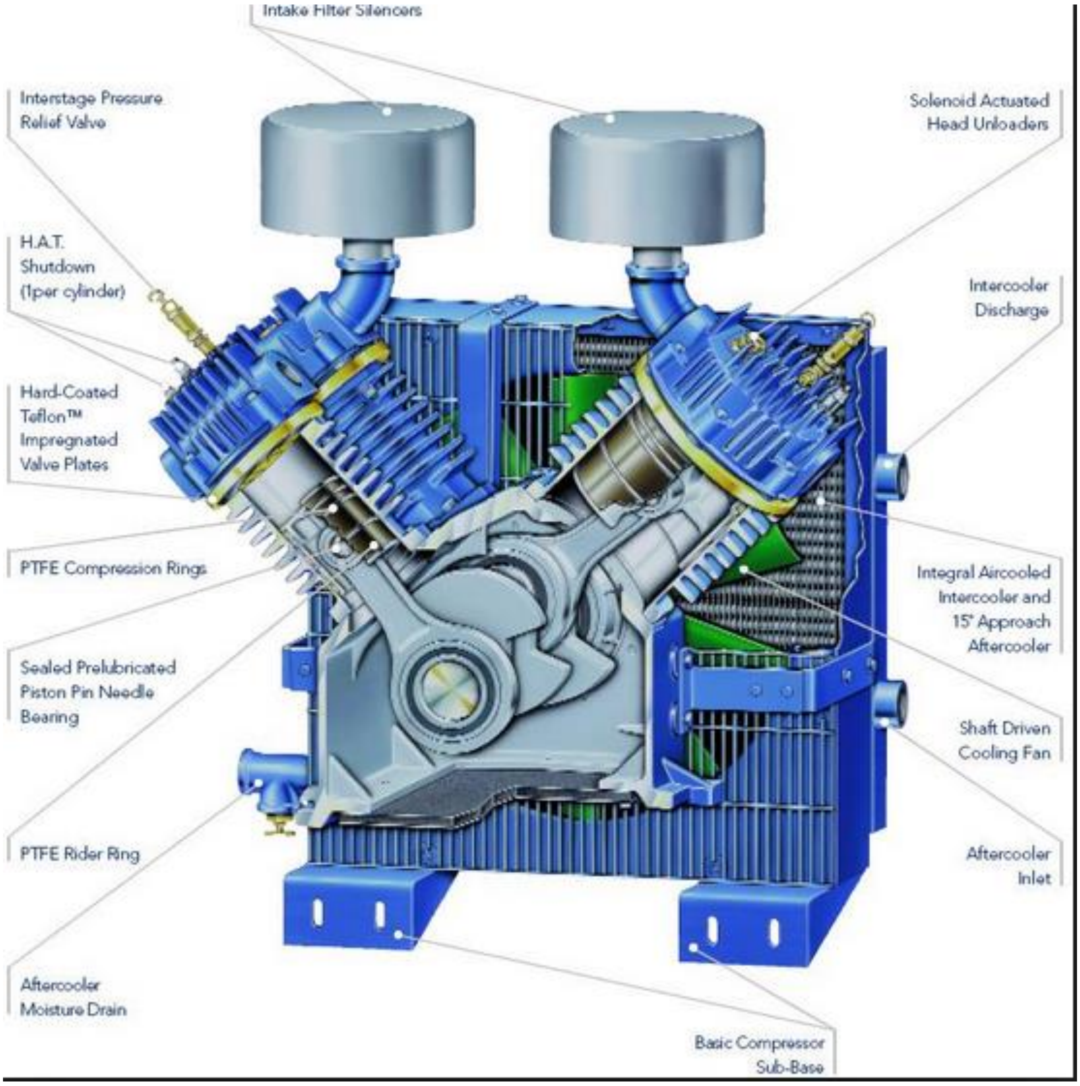
c) vane compressors
pressure range: 0,15 – 8,5 bar
flow: 250 – 15000 Nm^3/h

d) turbo compressors (= kinetic compressors)
pressure range: 0,7 – 4 bar (with 10 - 12 phase kinetic compressors even up to 20 bar)
flow: 60.000 – 500.000 Nm^3/h

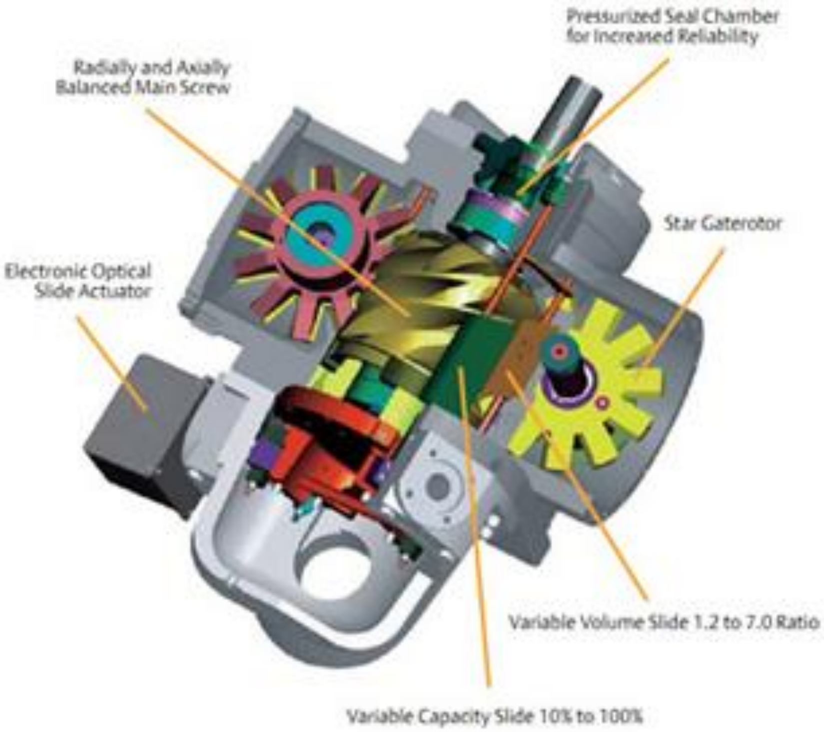
Piston compressors:

Reciprocating (Piston Type) air compressors use pistons driven by a crankshaft to compress the air.

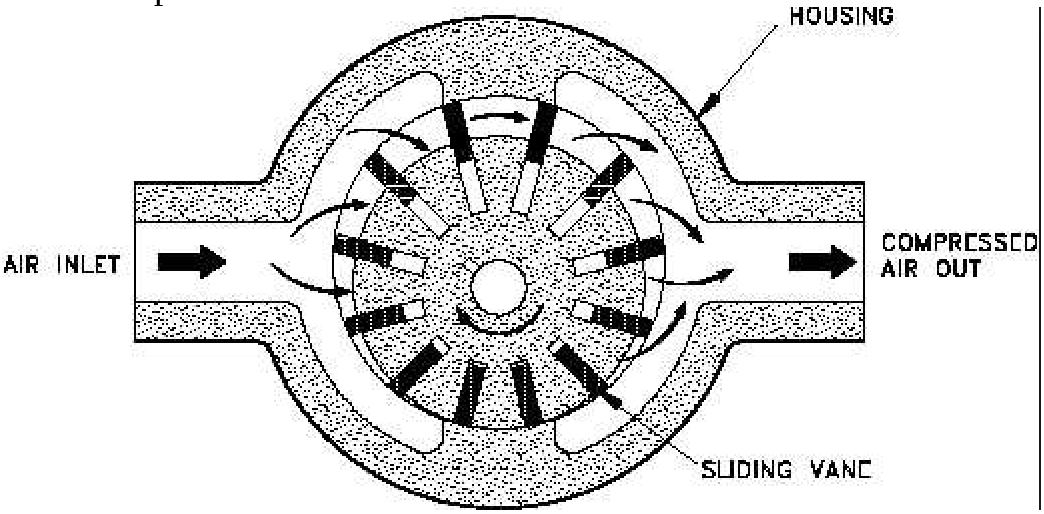


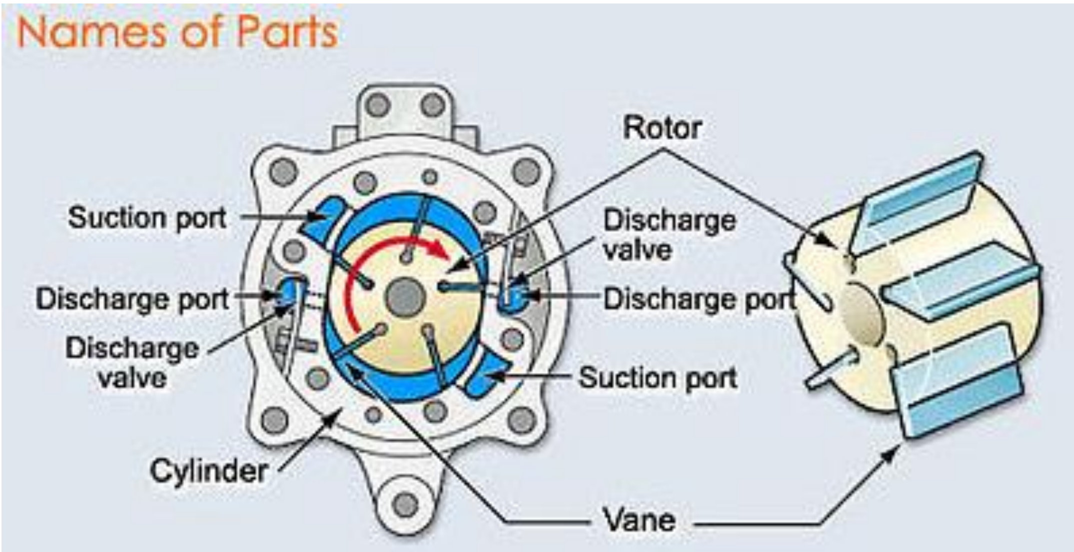


screw compressors:

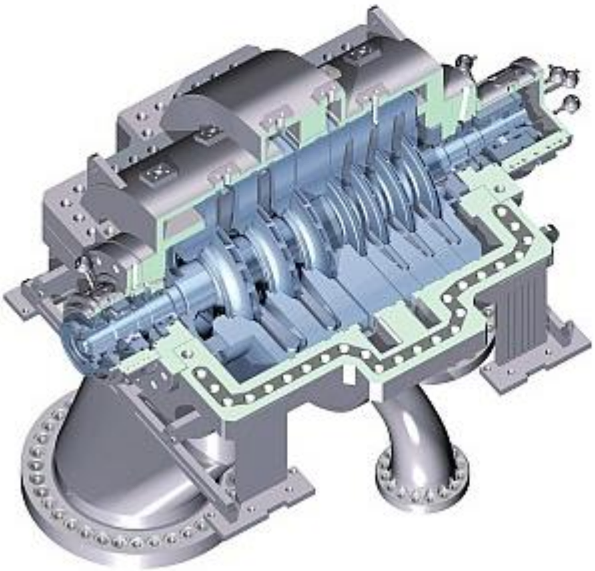

Pressurized Seal Chamber
for Increased Reliability
Radially and Axially
Balanced Main Screw
Star Gaterotor
Electronic Optical
Slide Actuator
Variable Volume Slide 1.2 to 7.0 Ratio
Variable Capacity Slide 10% to 100%

Vane compressors





Kinetic compressors:



Compressors manufactured by MAN Diesel & Turbo serve a wide range of industrial applications and are worldwide renowned for their quality as well as their high efficiency.

After treatment of compressed air

There are 6 – 9 quality classes of pressurized air according to ISO 8573-1.
The class is determined by the amount of impurities in the air. The impurities are divided into three groups: solid particles, water and oil.

Table 1 — Compressed air purity classes for particles

Class[a]	Maximum number of particles per cubic metre as a function of particle size, d[b]		
	0,1 µm < d ⩽ 0,5 µm	0,5 µm < d ⩽ 1,0 µm	1,0 µm < d ⩽ 5,0 µm
0	As specified by the equipment user or supplier and more stringent than class 1		
1	⩽ 20 000	⩽ 400	⩽ 10
2	⩽ 400 000	⩽ 6 000	⩽ 100
3	Not specified	⩽ 90 000	⩽ 1 000
4	Not specified	Not specified	⩽ 10 000
5	Not specified	Not specified	⩽ 100 000
Class	**Mass concentration**[b] C_p mg/m^3		
6[c]	$0 < C_p \leqslant 5$		
7[c]	$5 < C_p \leqslant 10$		
X	$C_p > 10$		

[a] To qualify for a class designation, each size range and particle number within a class shall be met.

[b] At reference conditions; see Clause 4.

[c] See A.3.2.2.

Table 2 — Compressed air purity classes for humidity and liquid water

Class	Pressure dewpoint °C
0	As specified by the equipment user or supplier and more stringent than class 1
1	⩽ –70
2	⩽ –40
3	⩽ –20
4	⩽ +3
5	⩽ +7
6	⩽ +10
Class	**Concentration of liquid water**[a] C_W g/m^3
7	$C_W \leqslant 0,5$
8	$0,5 < C_W \leqslant 5$
9	$5 < C_W \leqslant 10$
X	$C_W > 10$

[a] At reference conditions; see Clause 4.

Table 3 — Compressed air purity classes for total oil

Class	Concentration of total oil[a] (liquid, aerosol and vapour) mg/m^3
0	As specified by the equipment user or supplier and more stringent than class 1
1	$\leqslant$ 0,01
2	$\leqslant$ 0,1
3	$\leqslant$ 1
4	$\leqslant$ 5
X	> 5

[a] At reference conditions; see Clause 4.

The amount of impurities is controlled by different after treatment methods that are:

a) filteration
- depending on the application filteration accuracy can be between 0,1 – 40 µm

b) separation of oil
- oil comes from the compressor and it is removed with an active carbon filter

c) drying

The amount of water in compressed air is determined as a pressurized condensation point (=dew point). Applications require very different condensation points depending on their use and environment.

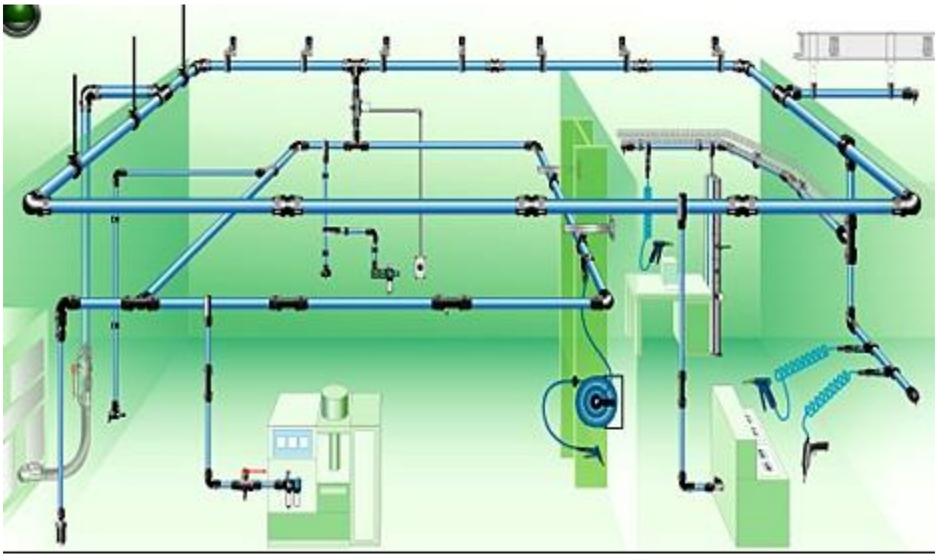
drying methods and typical condensation points:

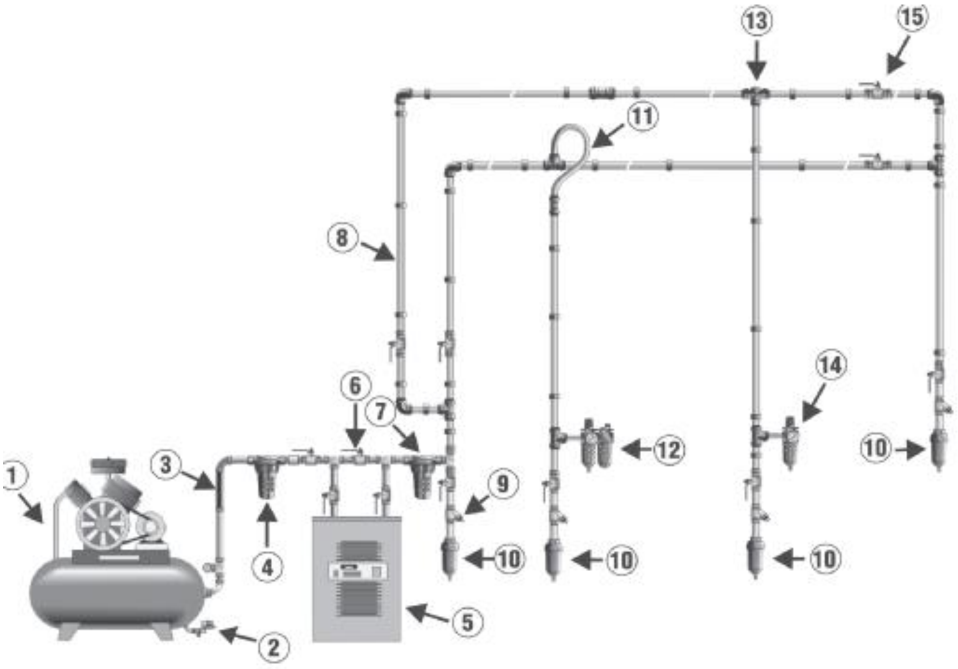
- after cooler -> condensation point +5 °C
- pressurization to higher pressure level -> c. point +10 °C
- absorption dryer -> condensation point +0 °C (a chemical method)
- adsorption dryer -> condensation point up to -40 °C (-60) (a physical method)

Principles of compressed air networks

a) Dividing by connected equipment.
   - Dry network including an air dryer has a free layout.
   - Wet network that has no dryer has limitations on the layout. The network must have angle of deflection about 2-3 degrees. It must have water separation equipments and all connections must be taken from upside of the pipe.

b) Dividing by shape of network.
   - Straight network. Biggest disadvantage is that during reparations the network is out of use.
   - Circle shape network. Pressure distribution is better. Part of the network can be separated for reparing and the other part can still be used normally.

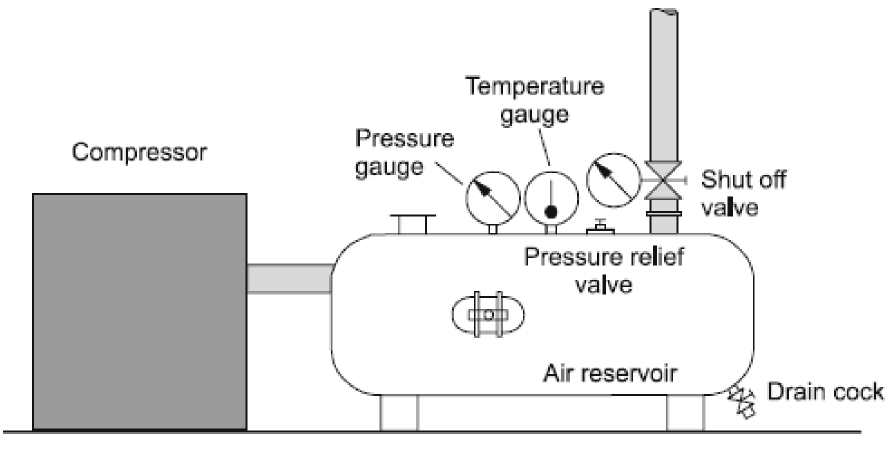




Functions of compressed air reservoir

1) to flatten out pressure peaks - that is pressure pulsation of the compressor
2) to even out comsumption peaks (= act as an accumulator)
3) to separate water
4) to act as reserve energy store during electric breakage

To select the size of a reservoir you must take into account: compressor flow, air usage maximum and control method of the compressor.




GEM
GEM
GEM

Dimensioning of piping

Dimensioning of the piping are made using calculations, tables or graphic methods presented in handbooks.

Matters that must be taken into account during dimensioning:
1) air usage
2) lenght of piping
3) working pressure
4) allowed pressure drop in piping (usually less than 10 kPa)
5) flow resistance of pipe (flow losses)
6) one-off losses (bends, corners, valves etc.)
7) recommended flow rate (with compressed air usually 6-20 m/s)

Piping materials

1. Steel; seamless, weldable with wire-wrap or welded joints
2. Brass or copper; in special cases/not common
3. Stainless steel; in process industry, expensive
4. Plastic; has not become popular allthrough it has several advantages like weight, price and lower flow resistance.

Service unit for compressed air

The unit consists of a filter, water separator, pressure controller, pressure gauge and oil mist lubrication system (used with special components only).

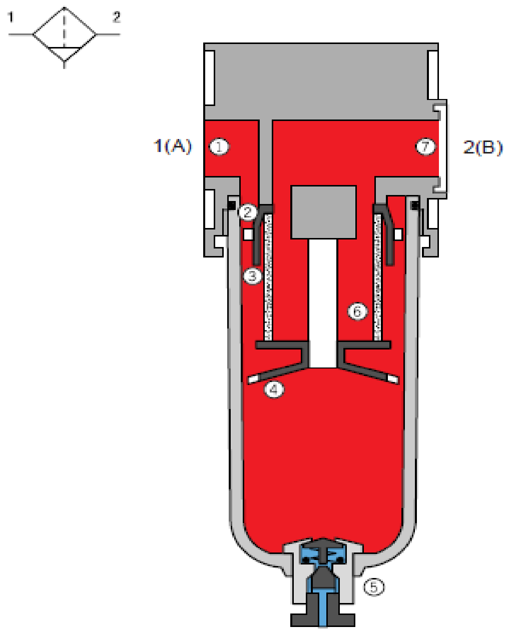
A filter separates solid particles and condensed water from air. Accuracy of filter elements with standard automation pneumatics is 20 - 40 µm. In low pressure pneumatics accuracy is about 5 µm and in special applications like food industry it is even 0,1 µm.
Service for filter is changing the element and cleaning the case. Water removal can be automatic or hand operated.

Pressure controller is actually a pressure reducing valve which sets the pressure level to certain level and keeps it constant.

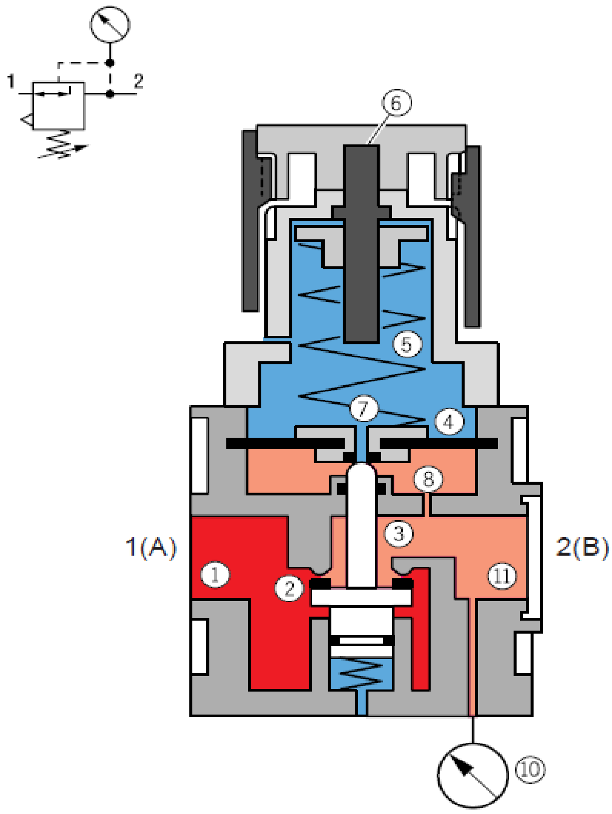
Oil mist lubrication systems uses low viscosity mineral oil. Most components today have permanent lubrication and need no oil mist.

Pneumatic motors and pneumatic power tools usually need oil lubrication to work properly.

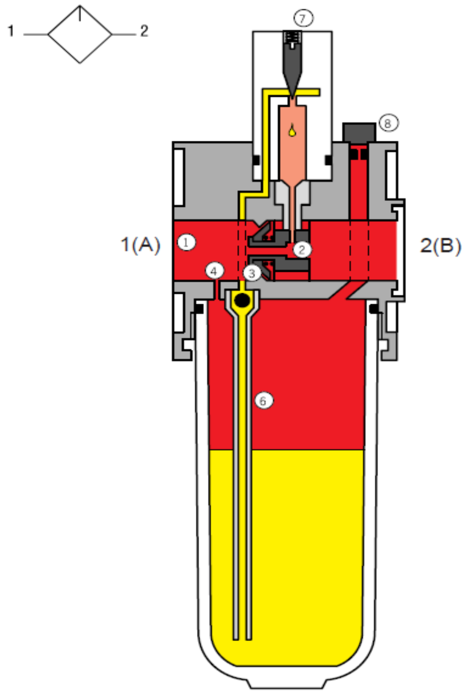
filter with water separator



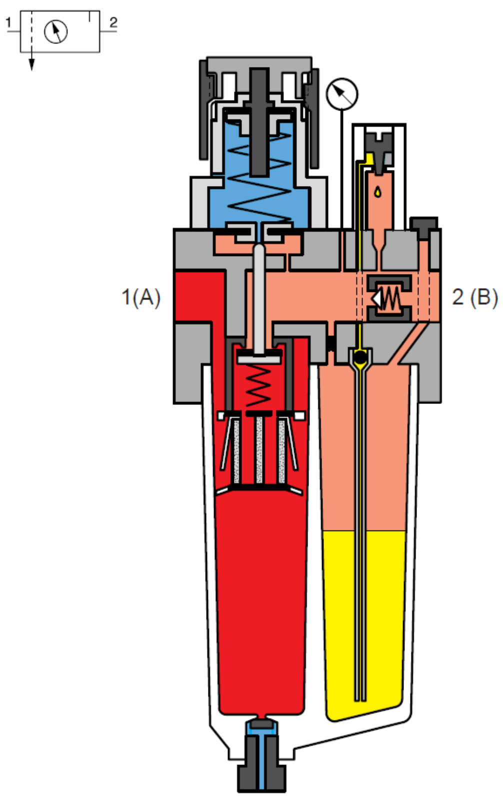
Pressure regulator



oil-fog lubricator



compressed air service unit



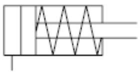
Cylinders

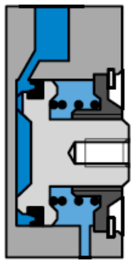
I) Single acting cylinders

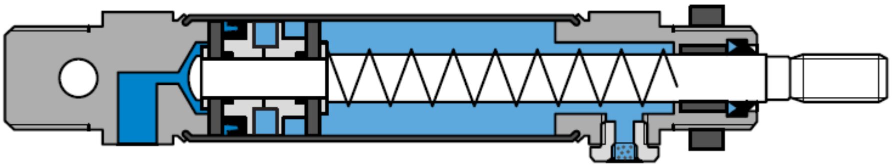
- only one direction of motion is performed with pneumatic energy
- return motion with a spring (or sometimes with an external force)

Configuration principles and typical values

a) Piston cylinders
- Piston Φ 6 – 200 mm (miniature even 2,5 mm)
- Stroke length usually < 100 mm
- Return motion is slow because spring force is small







b) Diaphragm cylinders
- Φ 20 – 600 mm
- Stroke lenght 2 – 50 mm
- Applications like presses, riveting machines, loaders (test machines)

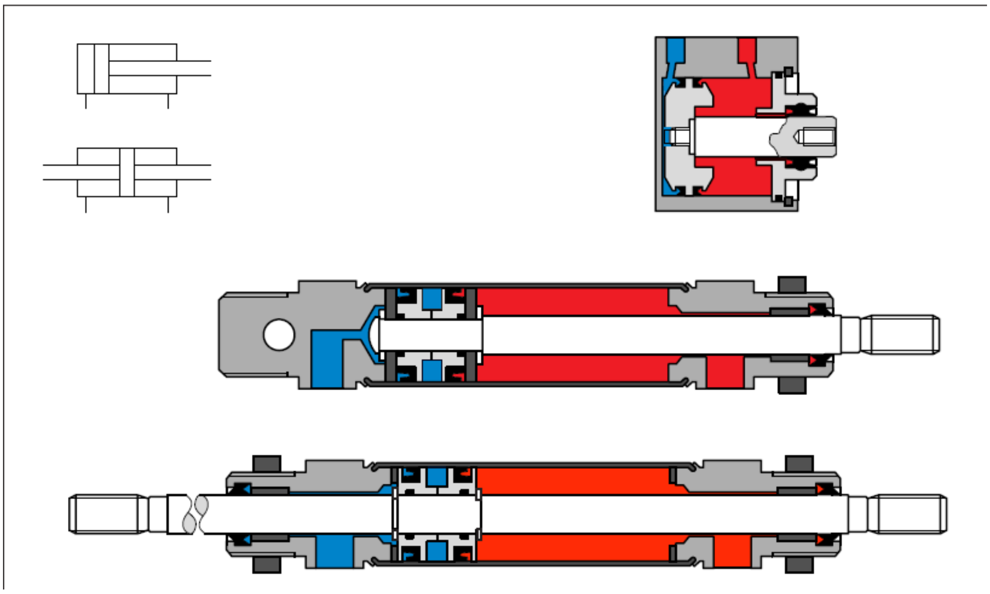
II) Double acting cylinders

- Piston Φ 6 – 320 mm
- ISO classification:

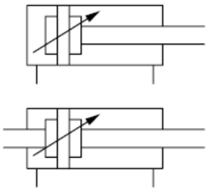
Light duty class: 8, 10, 12, 16, 20 and 25 mm
Medium duty class: 32, 40, 50, 63, 80 and 100 mm
Heavy duty class: 125, 160, 200, 250, 320 mm

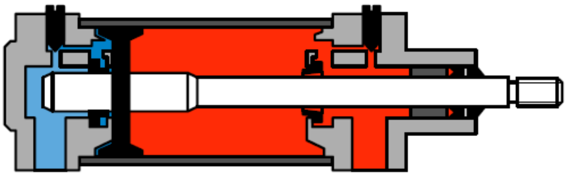
- Stroke lenght < 2000 mm (buckling danger)
- ISO stroke lenghts: 10, 25, 40, 50, 80, 100, 125, 160, 200, 250, 300, 400, ja 500 mm
- Piston speed typically < 1,5 m/s (in some robots even up to 10 m/s)
- Most common speed range is 0,3 – 0,6 m/s.
- If the piston speed is high and moving masses are significant end stroke attenuation systems are used to avoid structural damage to components.

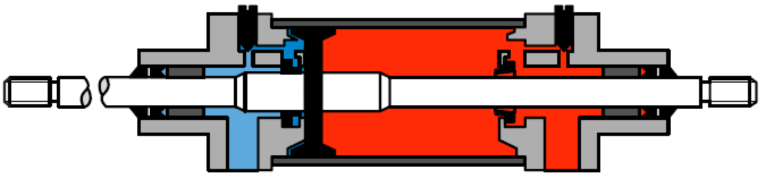
Cylinder, double acting



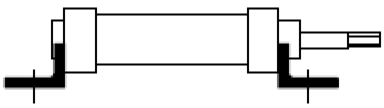
with stroke cushioning



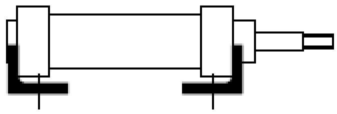




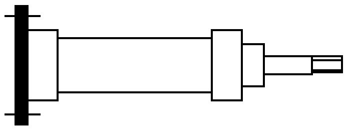
Cylinder mounting elements:



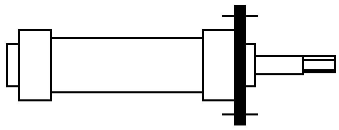
Foot mounting (outwards)
narrow or wide



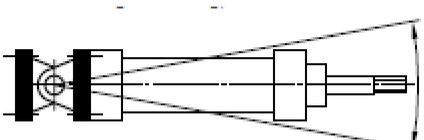
Foot mounting (inwards)
narrow or wide



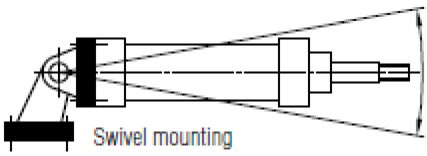
Flange mounting, rear



Flange mounting, front

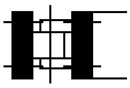


Swivel mounting



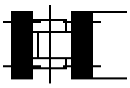
Swivel mounting

clevis-type



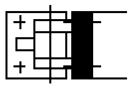
Counter-support
lug-type

lug-type

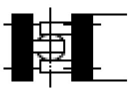


Counter-support
clevis-type

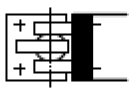
clevis-type



Counter-support
lug-type, 90° angle mounting

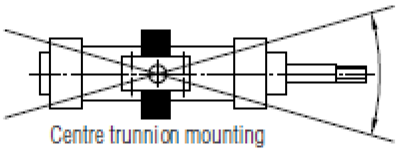


Counter-support
lug-type
(with swivel bearing)

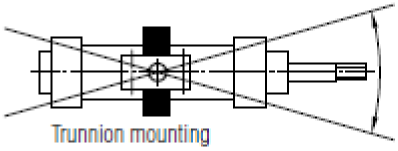


Counter-support
lug-type

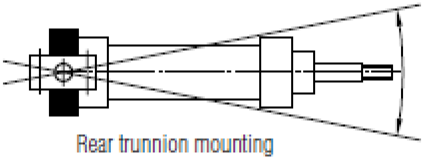
90° angle mounting
(with swivel bearing)



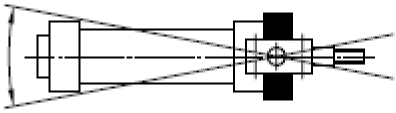
Centre trunnion mounting
(with swivel bearing)



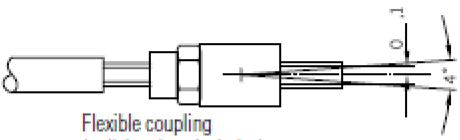
Trunnion mounting
(any position)
with swivel bearing



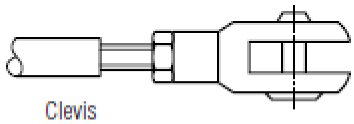
Rear trunnion mounting
with swivel bearing



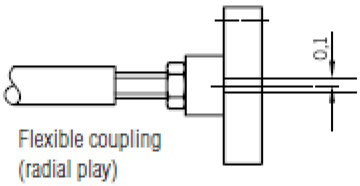
Front trunnion mounting
with swivel bearing



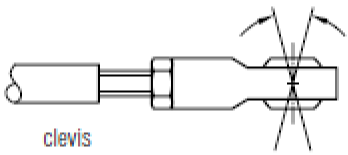
Flexible coupling
(radial and conical play)



Clevis



Flexible coupling
(radial play)



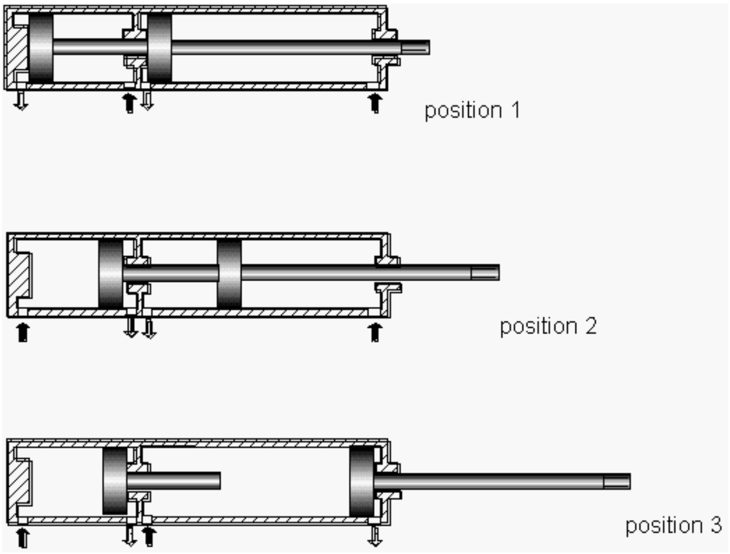
clevis
(sherical play)

Special cylinder structures

a) Double sided piston rod; same force for both directions, well supporting structure

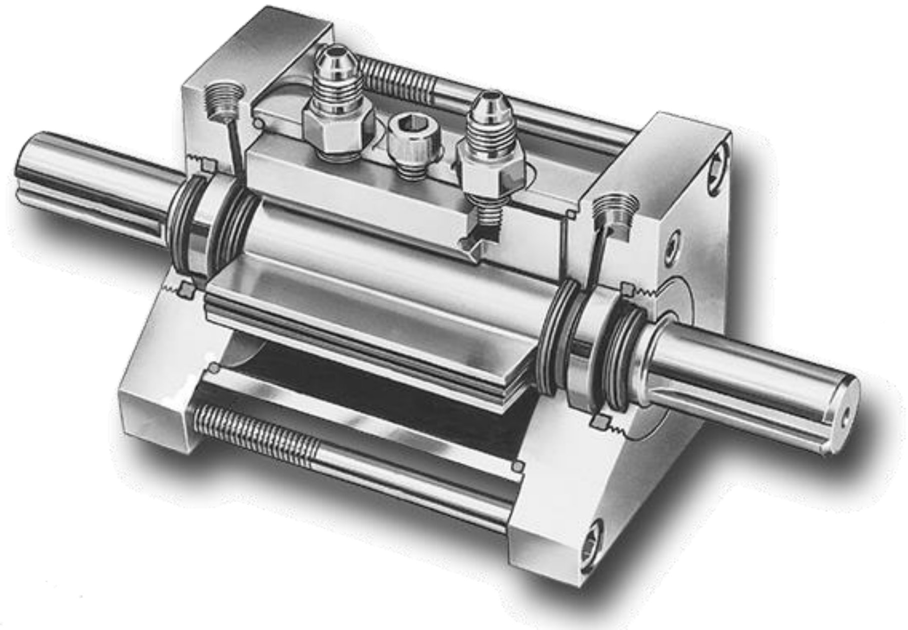
b) Tandem cylinder; two cylinder on the same axis and acting together to same direction, double force (almost), long structural length but diameter is small compared to the force

c) 3 or 4 position cylinder; two double acting cylinders attached their rear ends together, applications are sorting systems (= manipulator) in piece handling applications

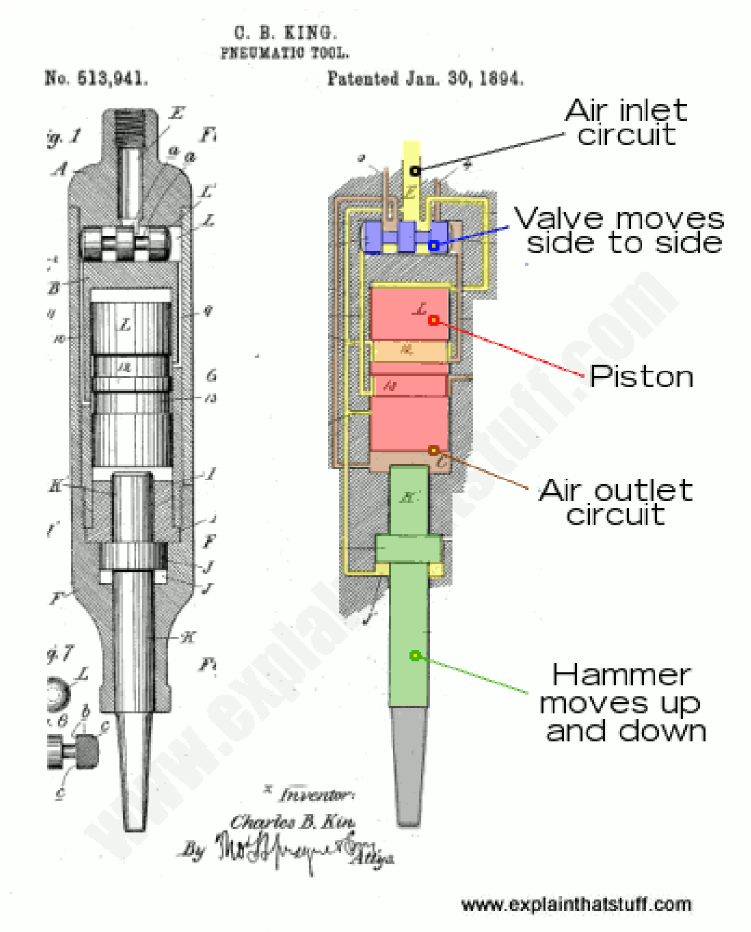


d) Torque cylinder; to rotate doors, valves, gates and lids etc.

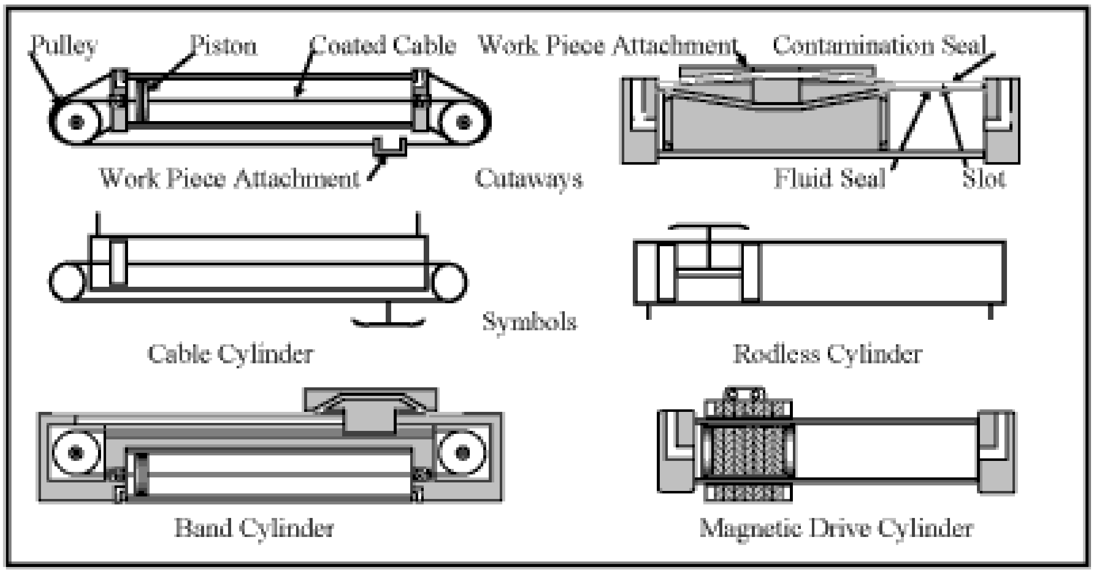
e) Rotary actuator; like a rotary vane motor with a limited turning angle, rotating angle between 45 and 270 degrees



f) Hammer cylinder; hammer like motion with high speed, rock driller, punching press, stamping machines



g) Rodless cylinders; material handling for very long strokes, manipulators, robots



Cylinder materials

1) cylinder body pipe:
- aluminium; different profiles
- steel
- stainless steel
- plastic or composites (still not common alltrough lower weight and friction)

2) cylinder ends:
- aluminium
- steel
- stainless steel

3) piston rod:
- compressed axle with hard crome plating
- stainless steel
- carbon fibre

4) piston:
- aluminium (especially with small cylinders)
- steel disc (with bigger cylinders)

5) seals:
- nitrile rubber -20…+80 °C
- polyurethane -20…+80 °C
- viton -20…+200 °C
- teflon -80…+250 °C

Pneumatic valve structures

1) Seat valves, ball and plate seat:
- short movement of valve stem
- fast operation
- full flow with even a small opening
- only few particles to wear
- long working life without any service needed
- quite a big operating force needed
- mainly small nominal sizes M5 – R1/4

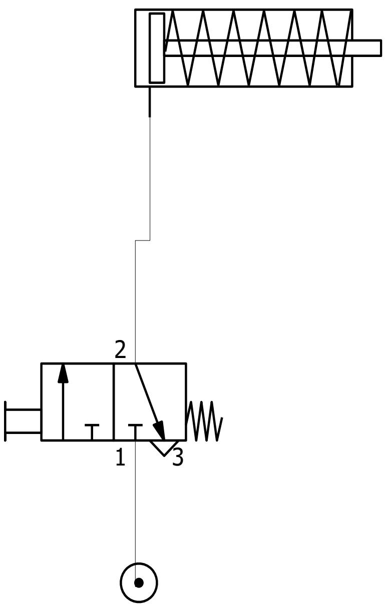
2) Spool valves:
- smaller operating force
- long spool movements
- slower operation
- working life shorter
- big nominal sizes are usually spool type valves

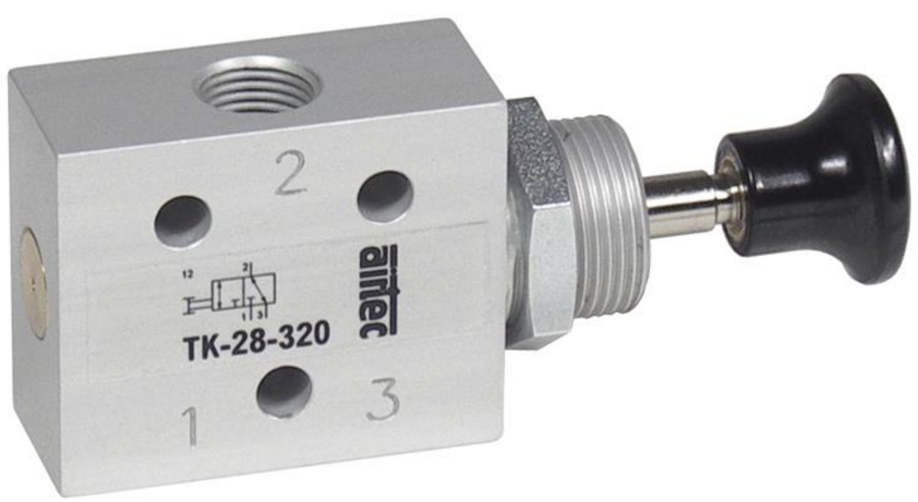
How to order a pneumatic valve

What properties must be known:
- number of connections and operating positions: 2/2, 3/2, 4/2, 5/2 valve etc.
- operating principle: hand, mechanic, pressure, electric operation
- spool or poppet return principle: spring, pressure, electric
- size of the connection
- pressure range (most pneumatics between 200…800 kPa)
- normal position, centre position
- exhaust connection type: without or with threads
- connection type: ISO subplate, pipe assembly etc.

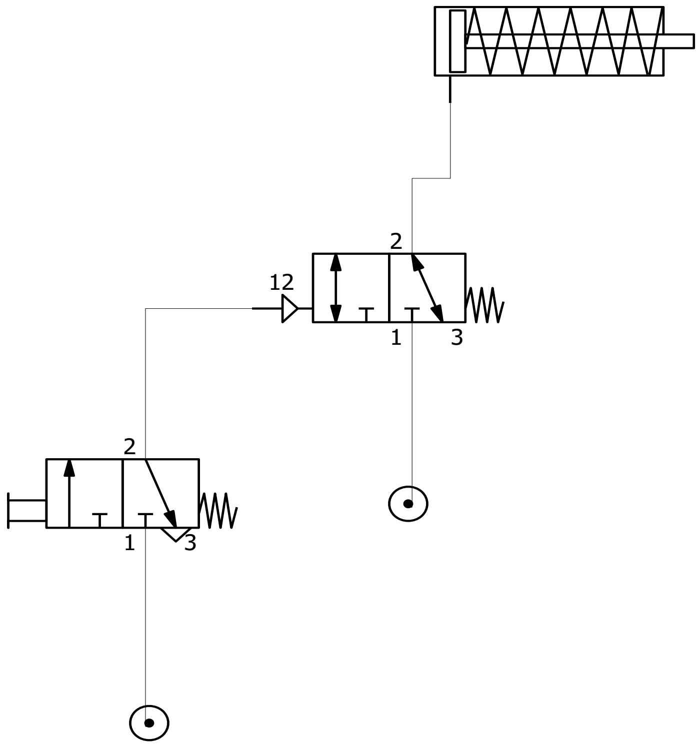
Basic pneumatic circuits

1. **Controlling of a single acting cylinder**
   - with a hand operated valve
   - return stroke with a spring
   - distance from cylinder to valve must be small (to avoid compressibility and slack operation)



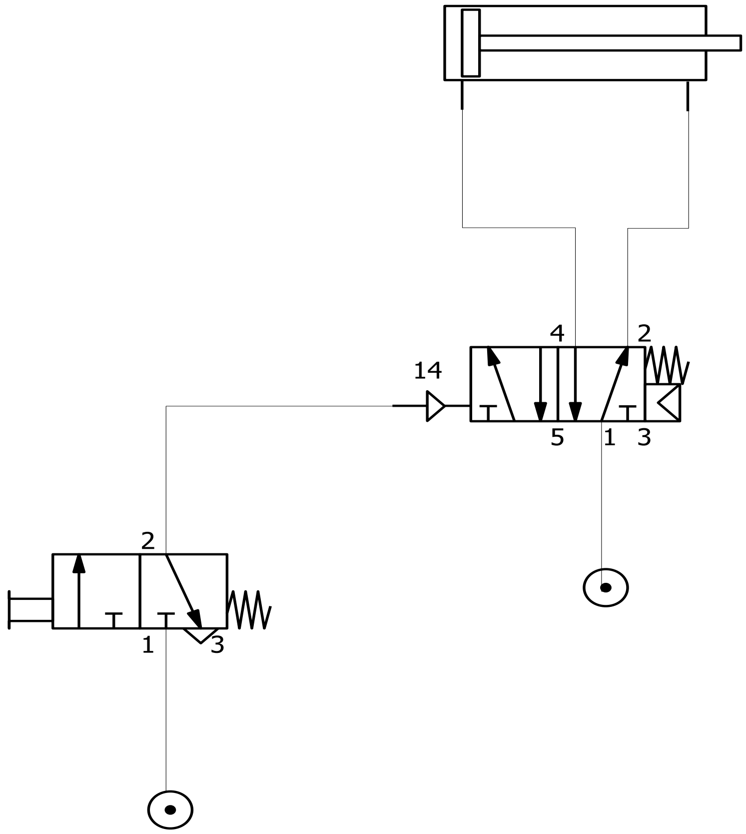


2. **Remote operation of a single acting cylinder**
   - hand operated; distance between valves can be big e.g. 100 m
   - signal time for 100 m is about 8 seconds -> so long pneumatic signal paths are not recommended
   - electric operation between valves is used instead
   - distance between cylinder and upper valve must be small (less than 2 meters)

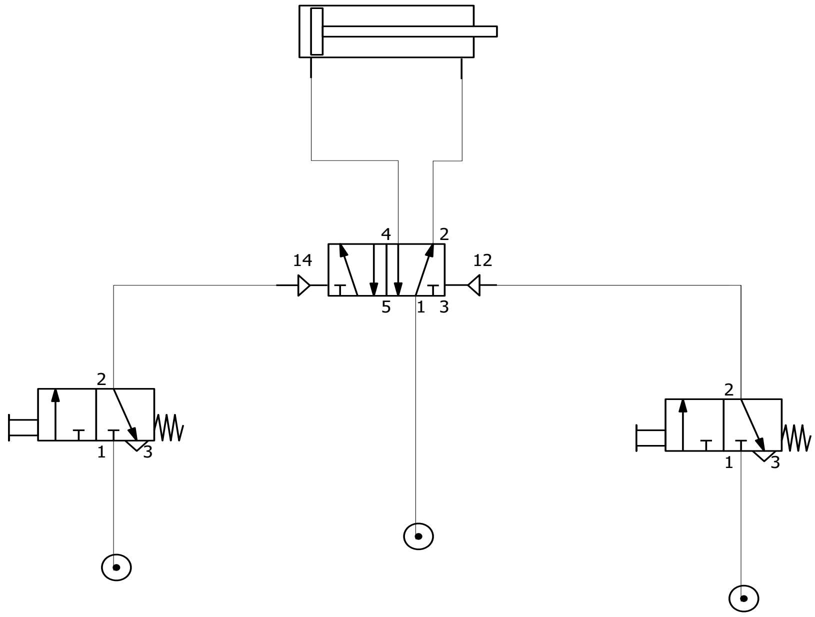


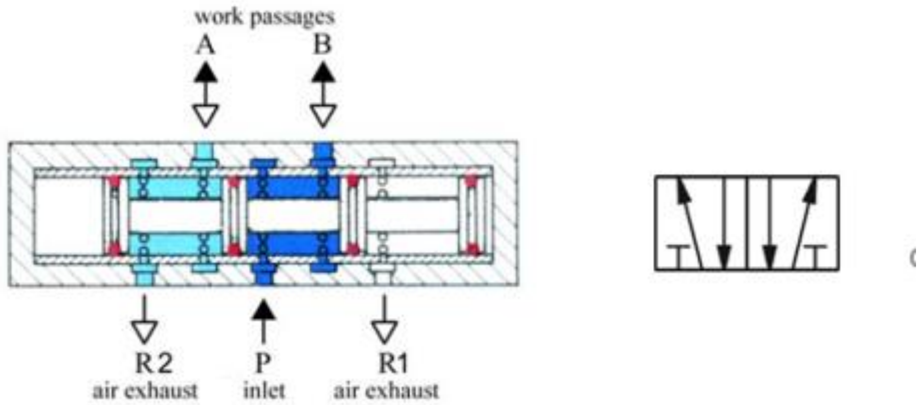
3. Operation of a double acting cylinder with a monostable control valve

- forward motion of cylinder happens when 3/2-valve is actuated by hand
- backward motion occurs when the signal valve is released and the control valve's (5/2-valve) position is returned to it's right position

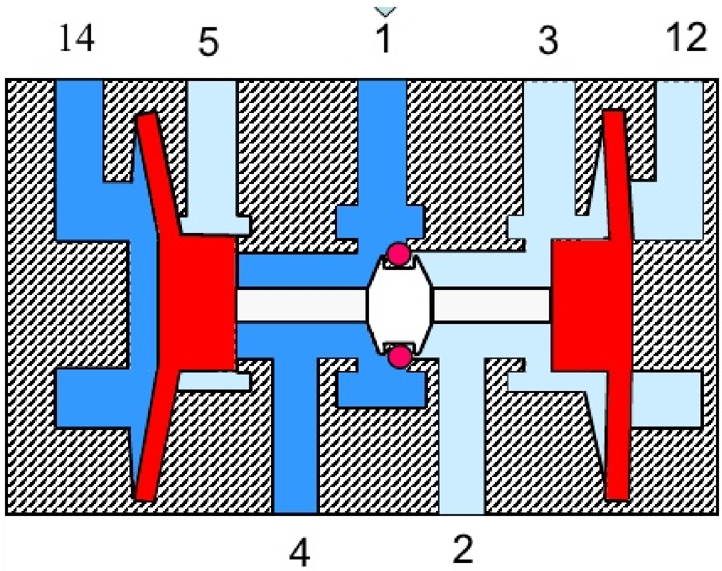


4. **Operation of a double acting cylinder with a bistable control valve**
   - A bistable directional valve has two stable positions.
   - When left signal valve is actuated (even shortly) left position of control valve comes on and cylinder makes its' forward motion.
   - Cylinder stays in its' extended position until right signal valve is actuated and return stroke occurs.

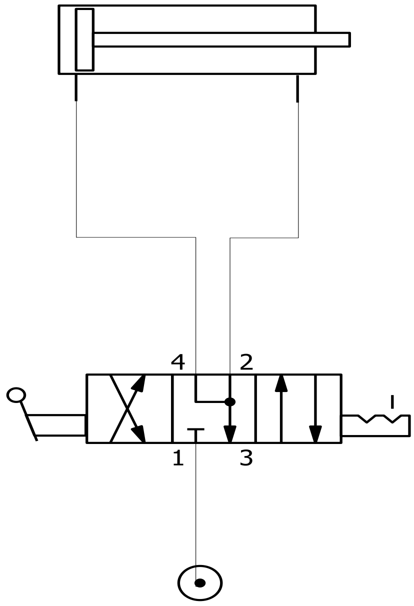


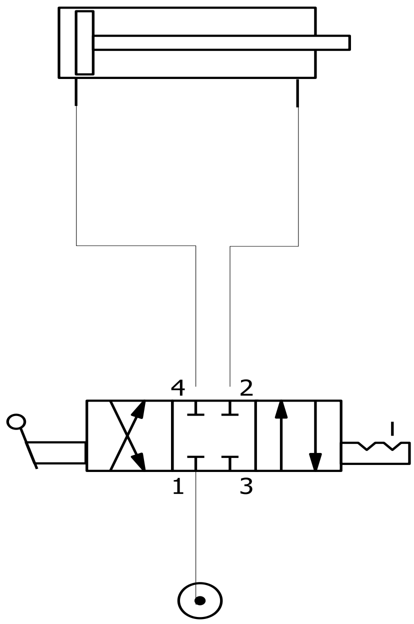


(b) Cross section (c) Pneumatic symbol

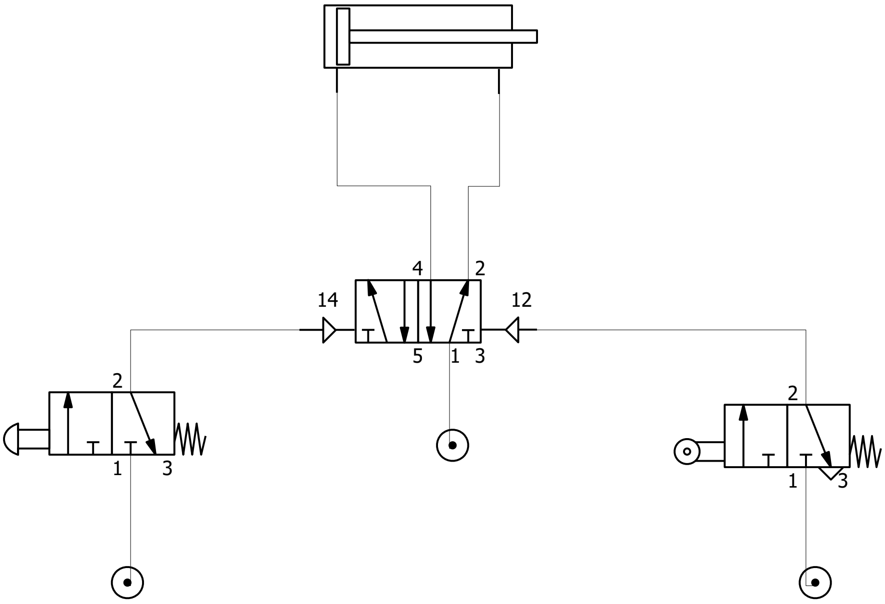


5. **Control of a cylinder with a 3-position valve 5/3-valve**
   - Used usually in applications that need an emergency stop system or need a release of actuator for possibility to do service work.
   - Upper figure to release the cylinder force. Lower figure to put the cylinder between two air cushions.





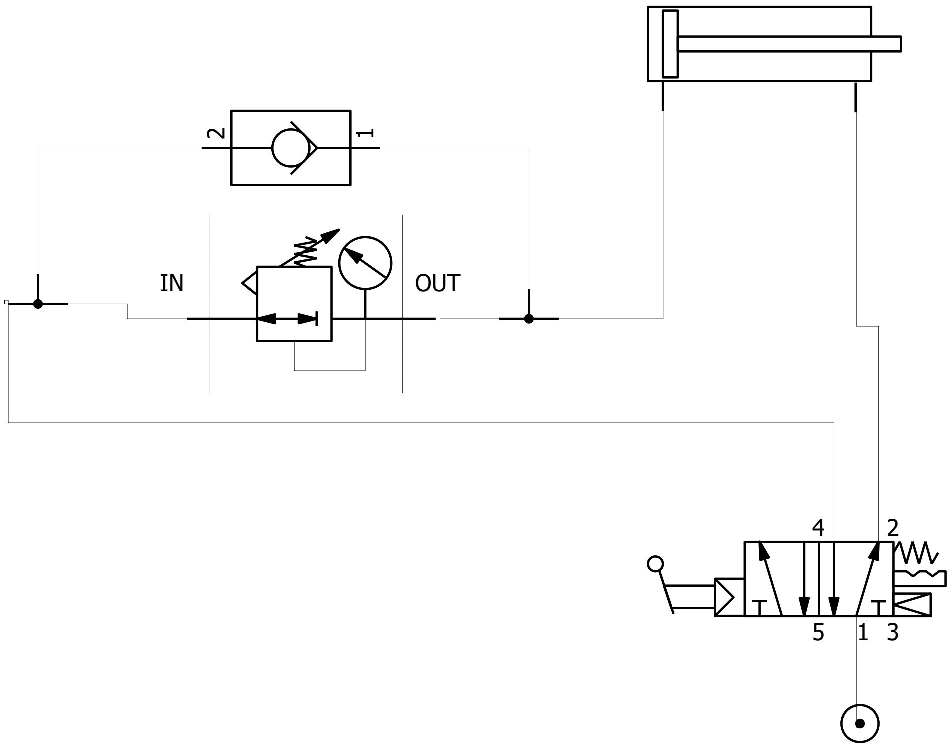
6. **Automatic return stroke of cylinder**
    - Right signal valve is physically located at the end of forward stroke.
    - Forward stroke of the cylinder is controlled by actuation of the left signal valve.
    - Cylinder piston rod mechanically actuates this right signal valve which moves the control valve to its' right position and return stroke happens.


4
2
14
12
5
1
3
2
1
3
2
1
3

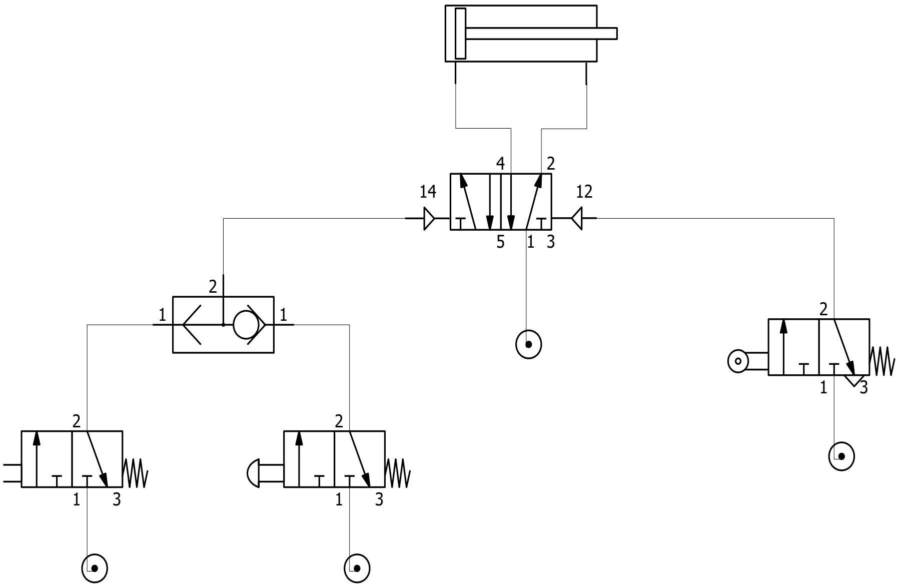

SMC
VM22

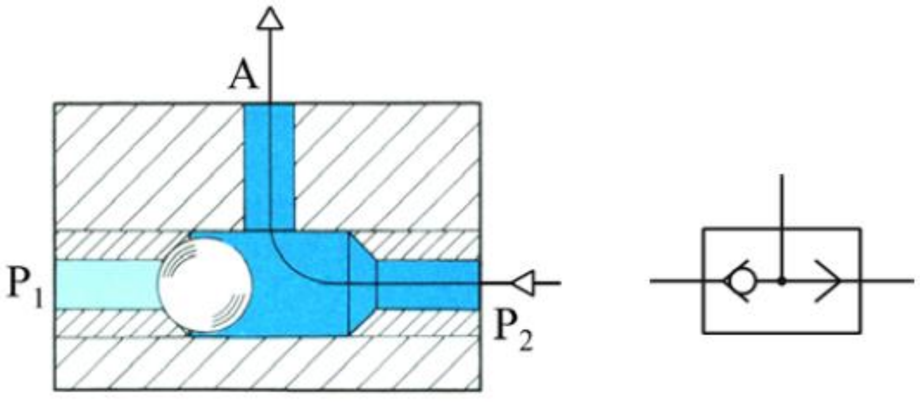
7. Controlling cylinder force

- Pressure reducing valve limit the pressure and thus the force achieved with the cylinder.
- Check valve must be there to enable return stroke.



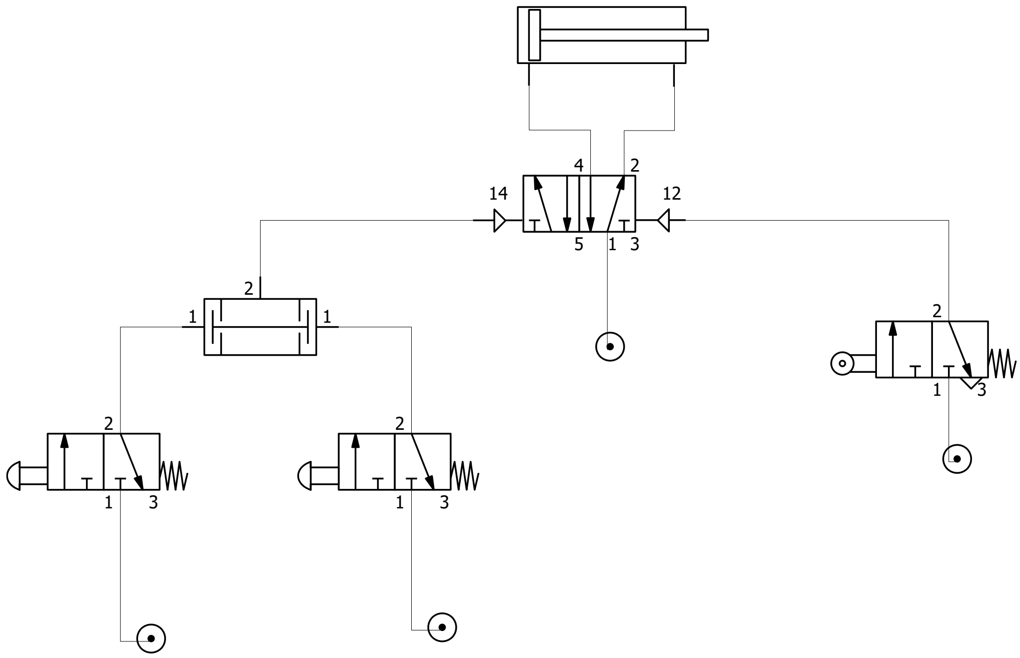
8. **OR-coupling e.g. alternative signal valves**
   - Shuttle valve (=OR gate or logic OR function) is used to control signal flow from two or more alternative signal valves.
   - There are two alternative signal valves to start the forward stroke
   - Automatic return stroke.





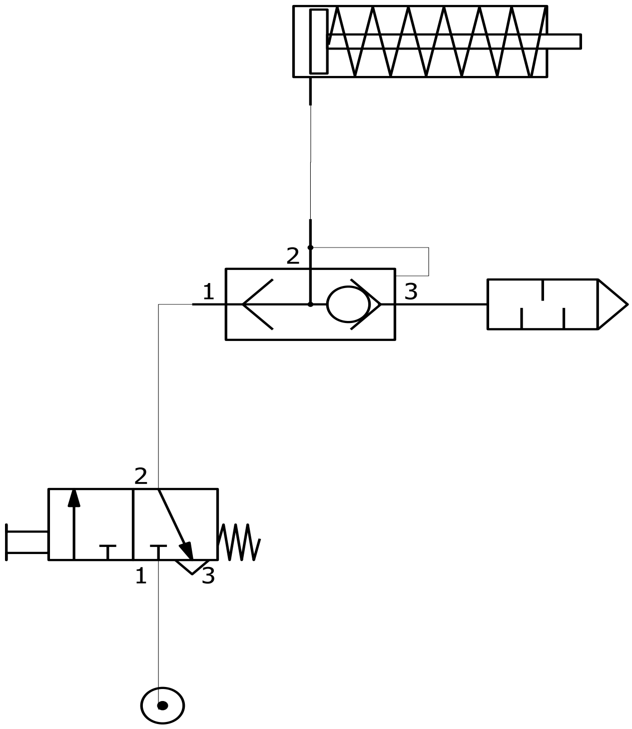
(b) Cross section (c) Pneumatic symbol

9. **AND-coupling control of cylinder**
   - AND-valve (=AND gate or logic AND function)) is needed for this circuit.
   - When both signal valves are actuated the AND gate gets pressures to both ends and signal goes through the gate. The signal then actuates the control valve and its' position changes to left box and cylinder does forward stroke.
   - Return stroke is automatic.



10. Quick exhaust valve to speed up stroke

- Quick exhaust valve is used between control valve and cylinder to make the stroke faster (= save time of total working cycle).
- Exhaust air is released through the quick exhaust valve with much less resistance. Back up pressure does not rise so much and does not counteract the movement so much as in normal case. The speed of the piston rises substantially.



Quick exhaust valves SE/SEU

FESTO

Key features, product range overview and type codes

Features

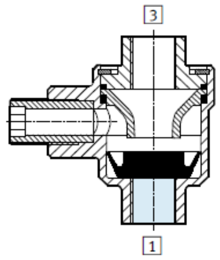
Function

These components allow higher piston speeds to be achieved on the return stroke of single and double-acting cylinders.
Compressed air flows from the pilot valve and via the quick exhaust valve to the cylinder. The exhaust port 3 is closed at this time. When the pressure at 1 falls, exhaust flow occurs from 2 to 3.

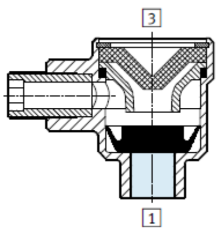
In order to achieve the full benefit of the quick exhaust function, the valve must be connected directly to the port of the cylinder.

In the quick exhaust valve SEU the exhaust noise is reduced by a silencer.

SE

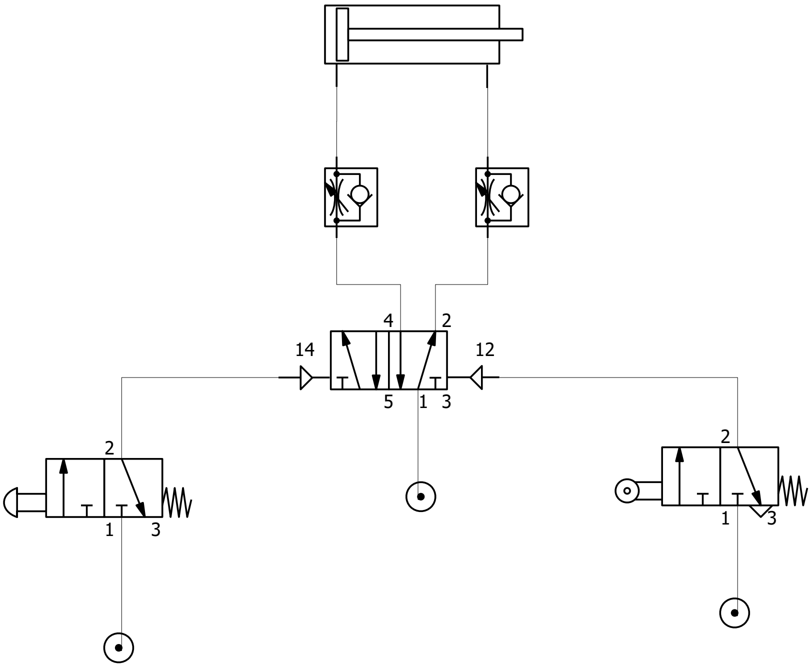


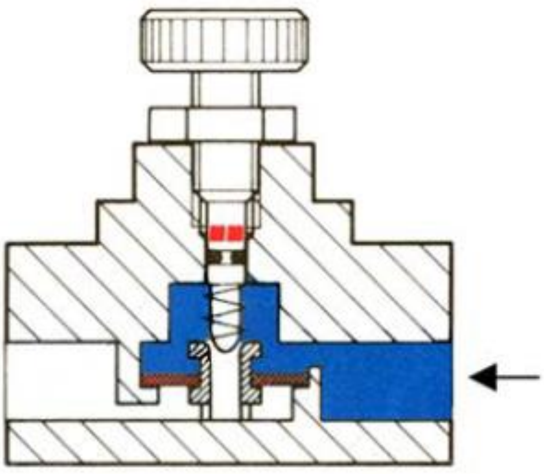
SEU

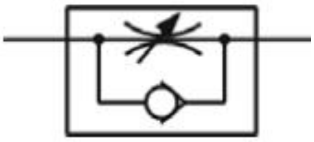


11. Cylinder speed control with a throttle check valve

- In a pneumatic circuit a throttle-check-valve is used to control the speed of the piston.
- The check valve is assembled in a way that the throttle valve adjusts the outgoing flow from cylinder. So the throttle is always in the return line.
- This throttle-check-valve is normally located in the cylinder port.

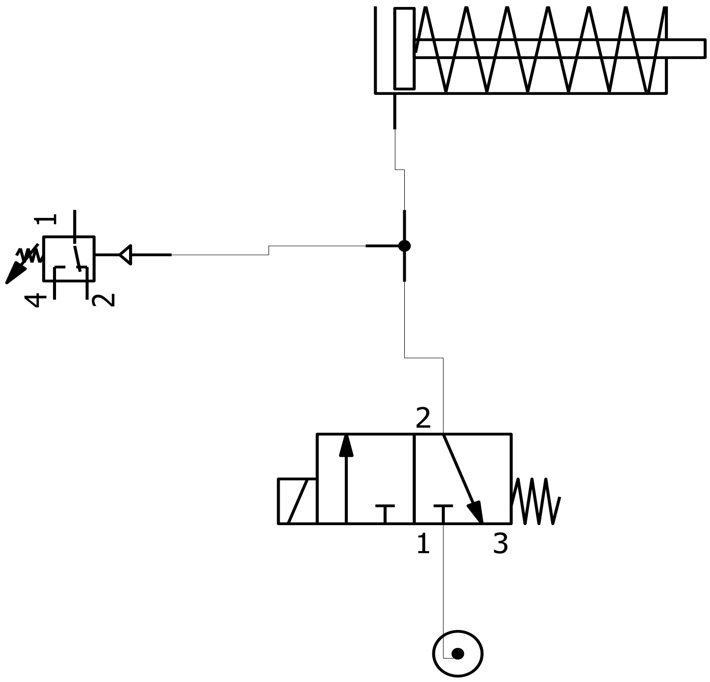






12. To secure a desired force with a cylinder

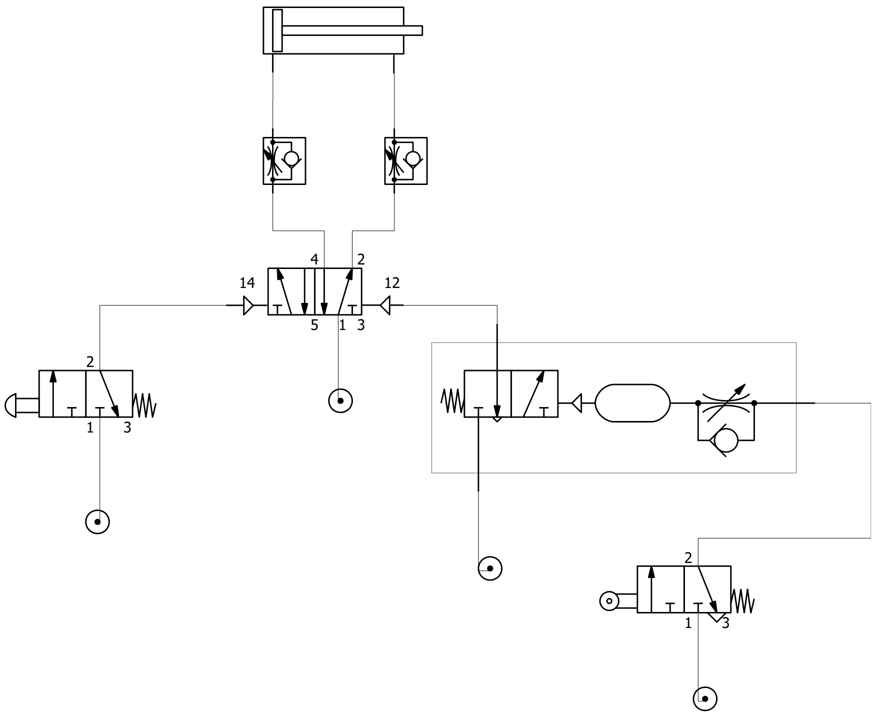
- A pressure switch is used in the circuit to start return stroke right after when the desired force (=pressure) has been achieved.
- Pressure switch gives electric signal to the control relay of the valve. Electric operation of valve.



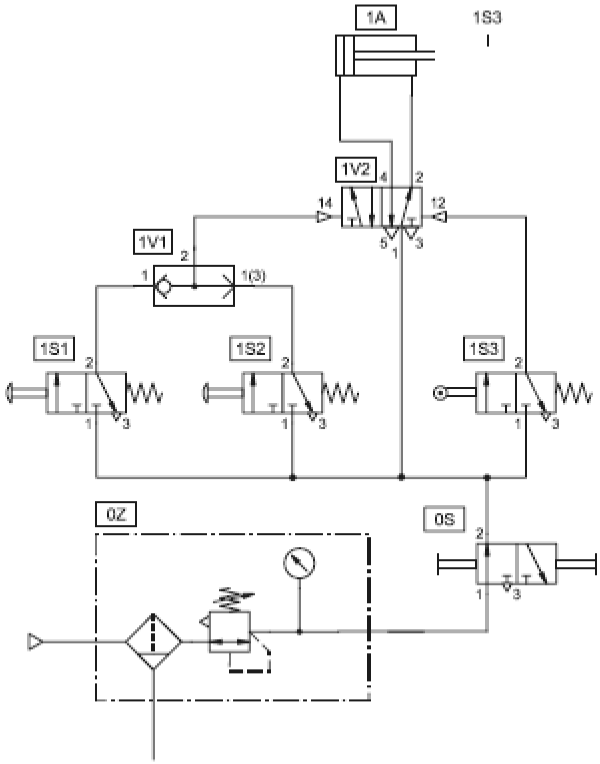
13.Time delay valve in a circuit

- Time delay valve is circled with dash line.
- Signal from right signal valve is delayed with time delay valve. After delay the signal goes to control valve and cylinder return stroke occurs.

- The length of time delay is adjusted with throttle valve.
- Controllable delay is between 1s…2min.

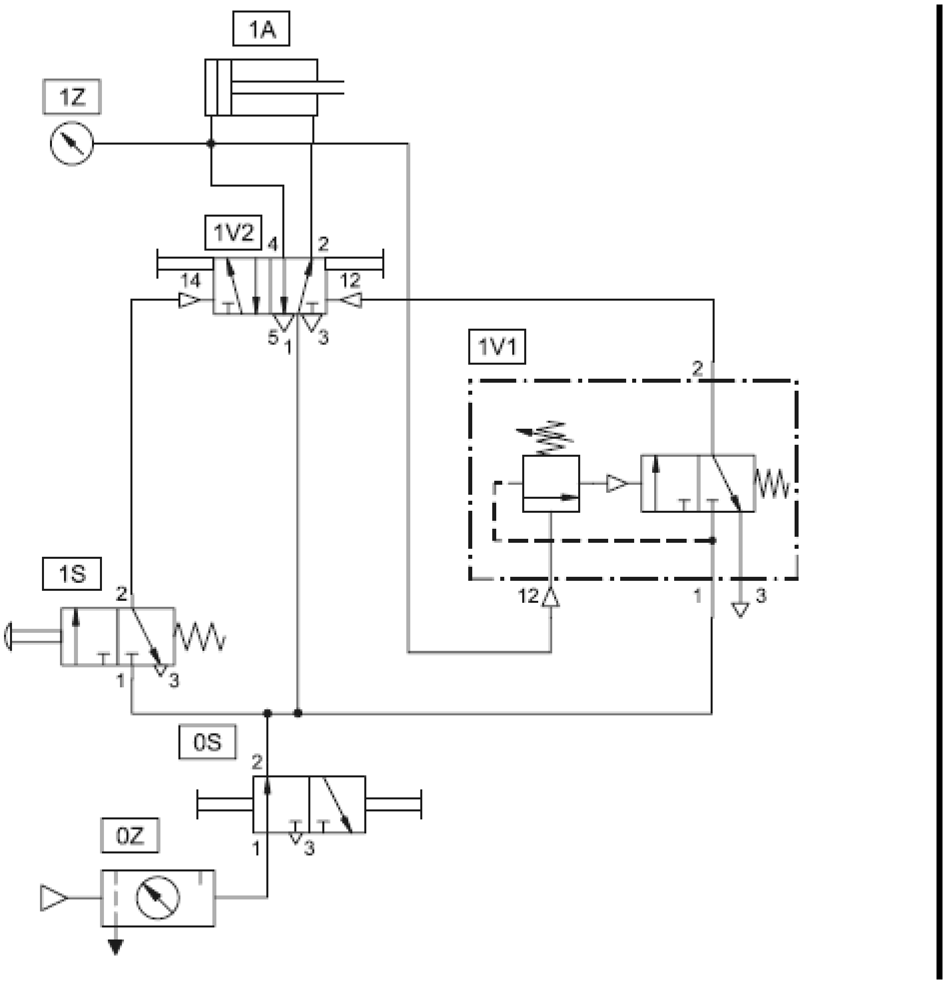


Other basic pneumatic circuits:



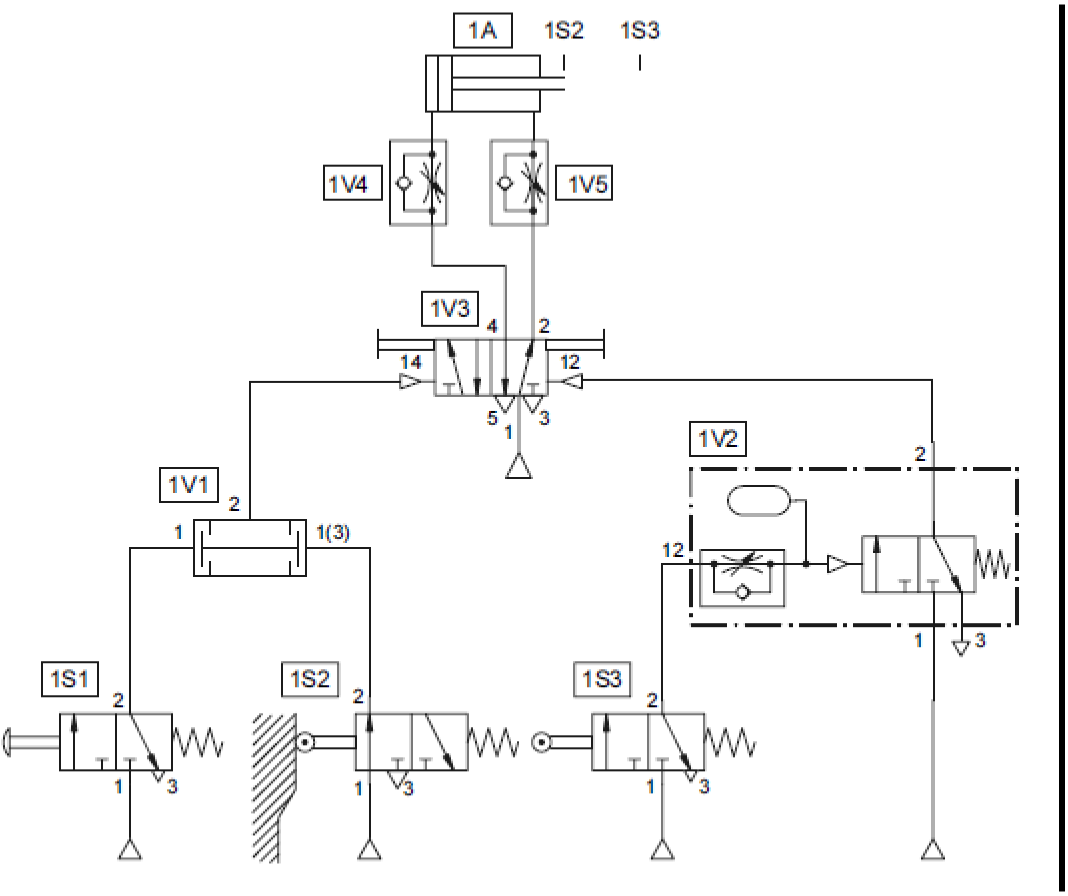
Pressure dependend control:

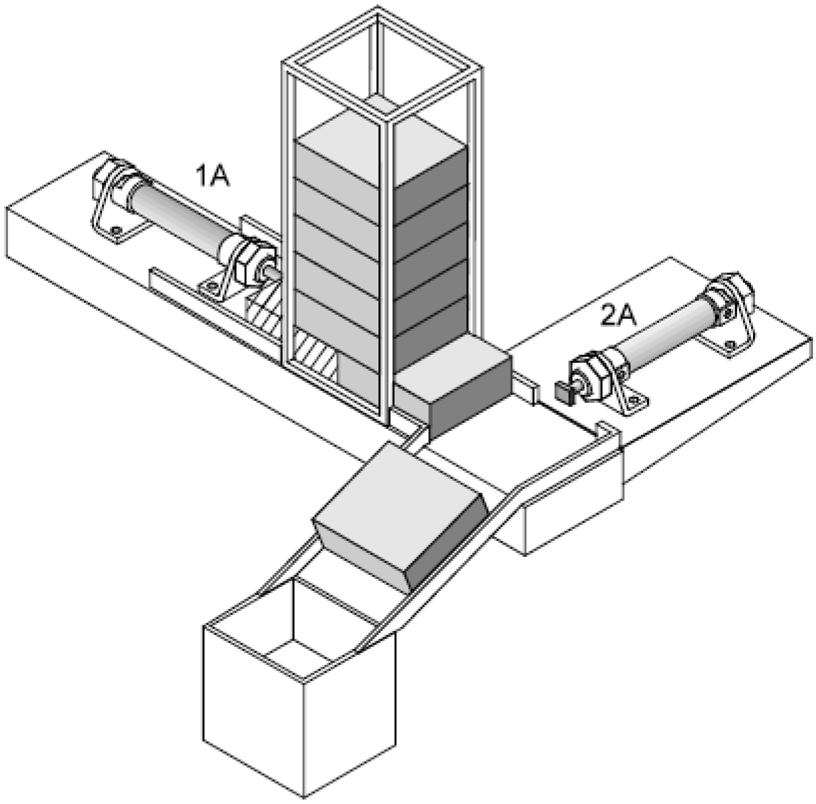
The control port 12 of the pressure sequence valve 1V1 is connected to the pressure line on the piston side of the cylinder 1A. When the pressure in the cylinder reaches the value set on the pressure sequence valve, the 3/2-way valve switches. A signal is now applied at the control port 12 of the valve 1V2. The valve 1V2 switches, pressure is applied at the piston rod side of the cylinder and the piston rod retracts. During retraction, the response pressure set on the pressure sequence valve is not met and the pressure sequence valve returns to its initial position.

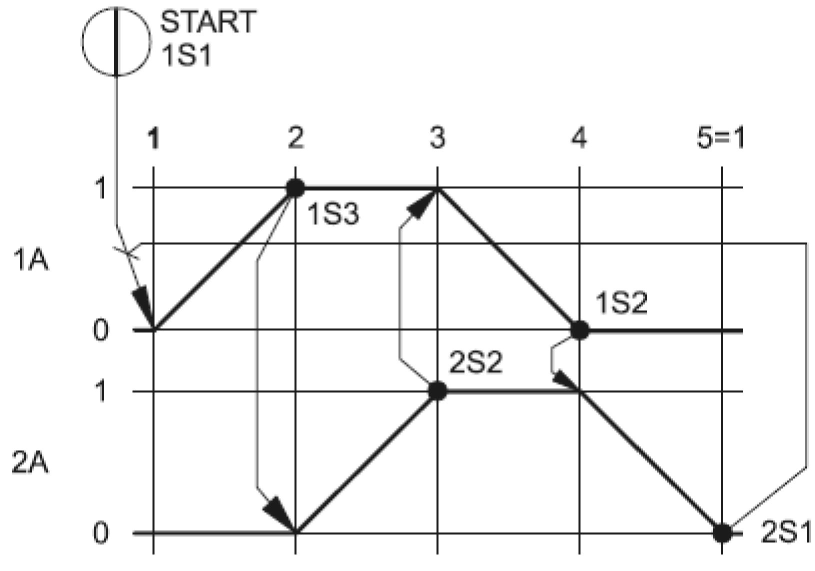


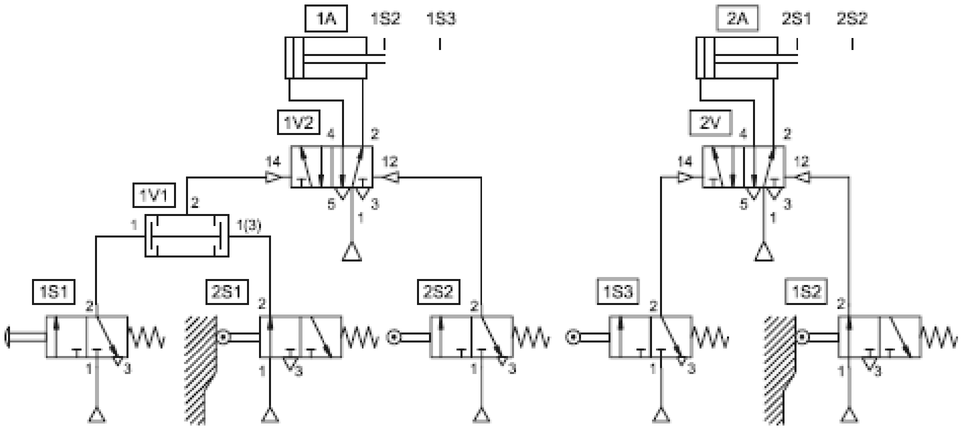
Time delay + AND function

Valve 1S1 and the limit switch 1S2 must be actuated as a start condition. The limit switch 1S2 is not actuated unless the piston rod is in its initial position. If the start condition is fulfilled, the dual-pressure valve 1V1 is switched to flow and a signal is applied at the control port 14 of the double pilot valve 1V3. The valve 1V3 reverses, pressure is applied at the piston side of the cylinder and the piston rod advances. The advancing speed is dependent on the setting of the one-way flow control valve 1V5 (exhaust air control). After a short advancing travel, the piston rod releases the limit switch 1S2.




1A
2A


START
1S1
1
2
3
4
5=1
1
1A
0
1
2A
0
1S3
1S2
2S2
2S1



Roller lever valves with idle return are to be used as limit switches to detect the return and advance positions of the piston rod. The manual signal input is effected via a 3/2-way valve.

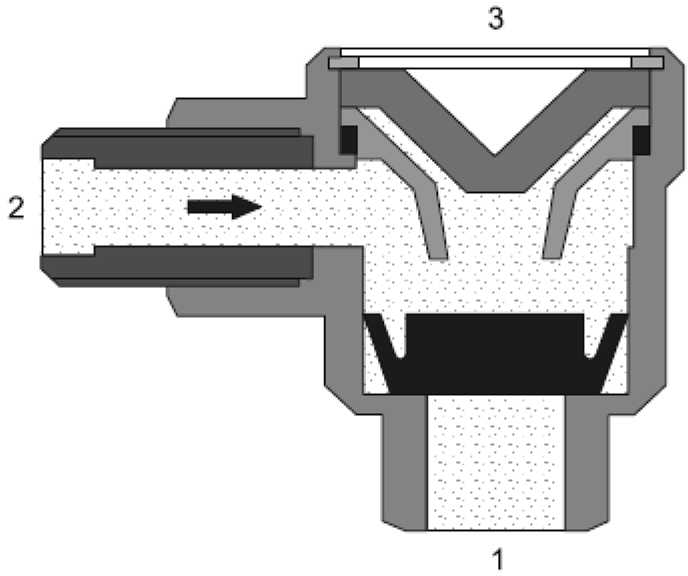
In the initial position, both cylinders are in the retracted state, the limit switches 2S1 and 1S2 are actuated.

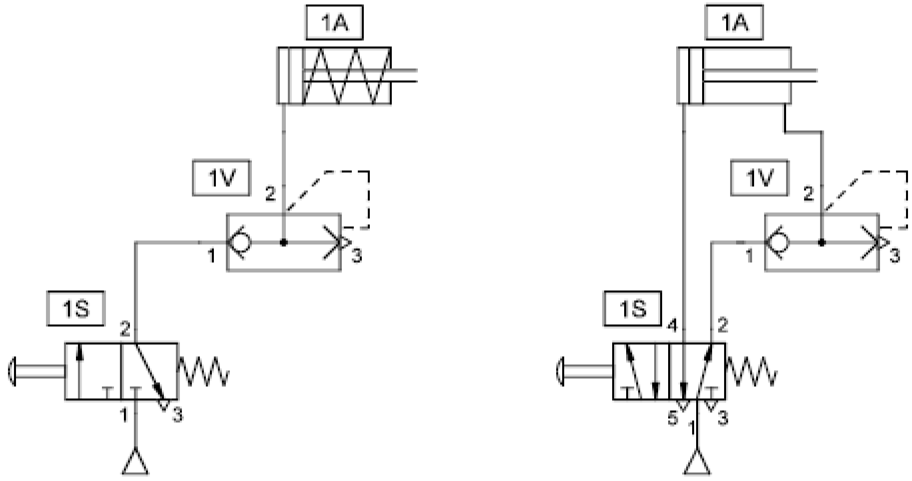
The start condition for a cycle is that the limit switch 2S1 and push button 1S1 must be actuated.

The motion cycle can be determined from the displacement-step diagram and is subdivided into the following steps:

Step 1	1S1 and 2S1 actuated	⇒	Cylinder 1A advances
Step 2	1S3 actuated	⇒	Cylinder 2A advances
Step 3	2S2 actuated	⇒	Cylinder 1A retracts
Step 4	1S2 actuated	⇒	Cylinder 2A retracts
Step 5	2S1 actuated	⇒	Initial position

Quick exhaust valve for rising piston speed of a cylinder

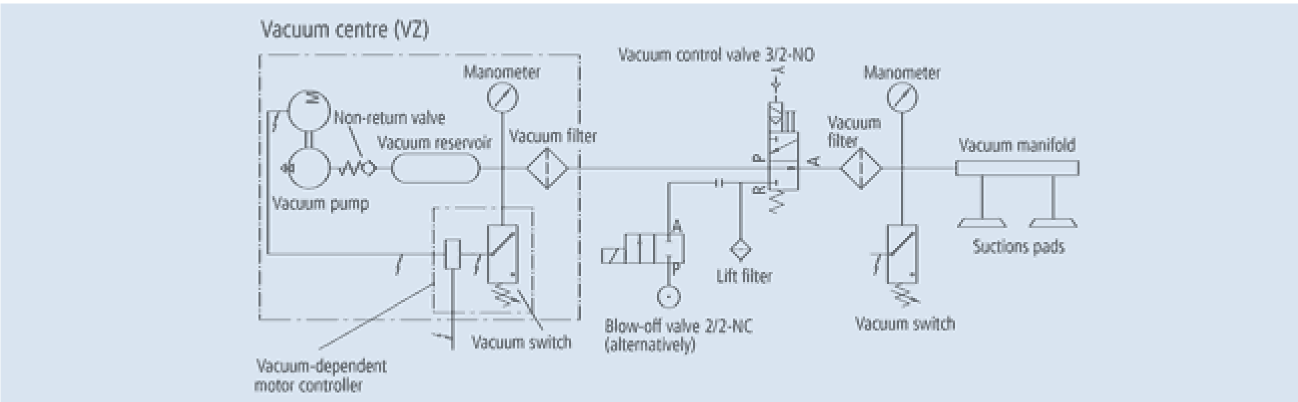




Pneumatic ejector and suction cups (pneumatic vacuum lifting/handling):

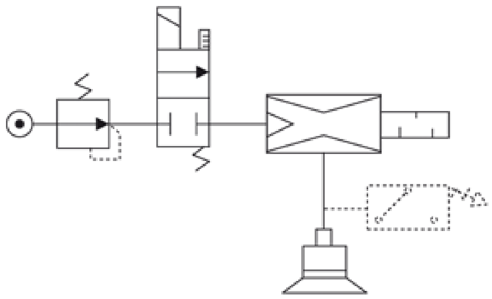
1Centralized

2Decentralized



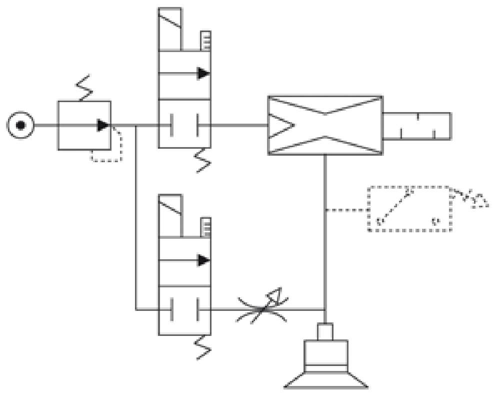
Vacuum centre (VZ)
Manometer
Non-return valve
Vacuum reservoir
Vacuum filter
Vacuum pump
Vacuum switch
Vacuum-dependent
motor controller
Vacuum control valve 3/2-NO
P
R
A
Blow-off valve 2/2-NC
(alternatively)
Lift filter
Vacuum
filter
Manometer
Vacuum manifold
Suctions pads
Vacuum switch

Ejector
with blow-off-function
EMM_ _ X _ _ EV _



> Basic product
> Only one control signal
> Display of vacuum level
> Manual control option

Ejector with controlled
blow-off-function
EMM_ _ X _ _ AV _



> Automatic blow-off through external signal, with adjusting screw
> Two control signals
> Display of vacuum level and blow-off-function
> Manual control option