

Pneumatik Training Course

Hafner-Pneumatik

Chapter 2:

The General Design of a Pneumatic System and its Components

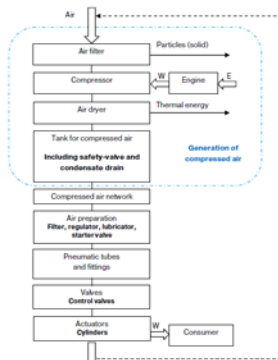


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The route of compressed air from its generation to the consumer

In pneumatics compressed air is utilized for performing mechanical work and for control. To do so we need different equipment to generate, treat and handle compressed air.

The graph displays the route of the environmental air from the compressor to the consumer of compressed air.



When designing a pneumatic system, typically the individual elements are distributed spatially dependent on their task. Although they are spatially separated, they are still connected systematically.

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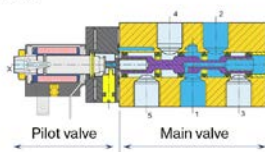
Chapter 4:

Structure and function of directional valves



2. Structure of pilot operated spool valves

Pilot operated valves (spool valves) consist of 2 parts. The graphic below shows the cross section of a 5/2-way spool valve.



The pilot valve is a 3/2-way poppet valve. The main valve is a 5/2-way spool valve.

The characteristics of the main valve are:

Basic design: spool valve

The axial movement of the spool opens and closes the route between distinct ports in the valve. The movement is provided by the energy of the compressed air.

Actuation: electrically (solenoid valve)

The pilot valve is electrically actuated. For its function see the explanation above.

Control: piloted

The pilot valve controls the pilot air which is taken from port 1 of the main valve and internally supplies the pilot valve. Port 2 of the pilot valve is connected to the top of the spool, triggering its movement.

Number of stable positions: one

The valve has one stable position. As soon as the electric signal is absent, the pilot valve exhausts the spool is pushed into basic position by either a mechanic spring or the force of the medium feed from 1 of the main valve to the back-end of the spool (called air spring). Sometimes a combination of both types of springs is used.

Basic position: Typically a 5/2-way valve is open from 1 to 2 and from 4 to 5. There is no such thing as "normally closed" or "normally open" for 5-way valves.

Number of ports and positions:

5/2, the valve has 5 ports and 2 positions.

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Chapter 7:

The pneumatic cylinder – part 1



We will look at the following characteristics:

1. Design
2. Diameter and stroke
3. Movement
4. Number of positions
5. ISO symbols
6. Cushioning
7. Detection of cylinder position (magnetic)
8. Speed control
9. International Standards

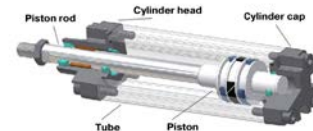
1. Design of a cylinder

Most of the cylinders with a piston rod contain the following parts: a tube that is closed on both ends with a cap and head. Inside the tube seen below a piston rod moves with a drive piston.

The movement of the piston is triggered by compressed air, controlled by a directional valve. The direction is defined by the chamber into which compressed air is allowed to flow inside the cylinder.

The force is transferred by the piston rod.

Components of a piston rod cylinder:



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Chapter 1:

Basic Concepts of Pneumatics



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Chapter 1:

Basic Concepts of Pneumatics



What is pneumatics?

Pneumatics is the utilization of compressed air in science and industry in order to perform mechanical work and control. We can either talk about pneumatics or pneumatic systems.

In this course we define pneumatics as the **control and transfer of power by using compressed air**.

Advantages and Disadvantages of Compressed Air

Pneumatic systems have **numerous advantages**, the most important of which are:

- The medium, compressed air, can be easily extracted from our environment. There is no lack or shortage of it.
- After usage the compressed air goes back to its original condition. It can be released into the environment.
- Air can be compressed flexibly. Therefore it is ideal for absorbing shocks and vibrations.
- The distribution of compressed air can be easily handled with pipes and hoses.
- Compressed air can be used in fire- and explosion-hazardous environment.
- Both its pressure level and volume can be regulated quite easily. Therefore the energy brought to the actuator can also be controlled quite easily and within broad parameters.
- The usage of pneumatic components is easy as well as their maintenance. Their functionality is generally very reliable.

Besides these advantages there are some **typical disadvantages**:

- Compressed air – depending on its application – needs some preparation, especially filtration and drying.
- Because of pricy electric energy and the limited efficiency of compressors, compressed air is a relatively expensive means of energy.
- Because of air's compressibility, the precise and load-independent positioning of the actuator(s) is not possible.

Chapter 1:

Basic Concepts of Pneumatics



Physical Fundamentals and Units of Measurement (metric system)

The SI-system of units is based on numerous basic and derived units of measurement. We do not cover that in detail. [**International System of Units**, short **SI** (french): *Système international d'unités*]

Units of measurement that are relevant in pneumatics:

- Meter – **m** (length / distance)
- Kilogram – **kg** (weight / mass)
- Second – **s** (time)
- Kelvin – **K** (temperature)

Derived units that are used:

- Newton – **N** (force)
- Pascal – **Pa** (pressure)

Force

Force is any interaction that, when unopposed, will change the motion of an object. In other words, a force can cause an object with mass to change its velocity (acceleration, change of shape). Force can also be described as a push or pull. It is a vector quantity consisting of magnitude and direction.

- Symbol: **F**
- Unit: **Newton**
- Unit symbol: **N**
- In SI-based units: $\frac{kg \cdot m}{s^2}$

Chapter 1:

Basic Concepts of Pneumatics



Pressure

Pressure is the force applied perpendicular to the surface of an object per unit area over which the force is distributed.

$$p = \frac{F}{A}$$

- Symbol: **P**
- Unit: **Pascal**
- Unit symbol: **Pa**
- In SI-based units: $\frac{N}{m^2}$

For measuring pressure, the following multipliers are common:

1 **kPa** (Kilopascal) = 1,000 Pa

1 **MPa** (megapascal) = 1,000,000 Pa

In pneumatics we normally use the unit **bar**.

1 **bar** = 100,000 Pa = 0.1 MPa = 0.1 N/mm²

1 **mbar** = 0.001 bar

1 **nbar** = 0.000000001 bar

In some countries such as the USA or Great Britain the unit **psi** (pounds per square inch) is also still in use.

1 **psi** = 0.07 bar (rounded)

Standard atmospheric pressure is the pressure of the air on sea-level, which equals 1 atm (atmosphere).

1 **atm** = 101,325 Pa = 1013.25 mbar (*Millibar*) or hPa (*Hektopascal*)

This unit is normally used in meteorology. Rounded and precise enough for most applications:

1 atm = 1 bar

Excess pressure or gauge pressure is the value of pressure above standard atmospheric pressure. It is also called **relative pressure**.

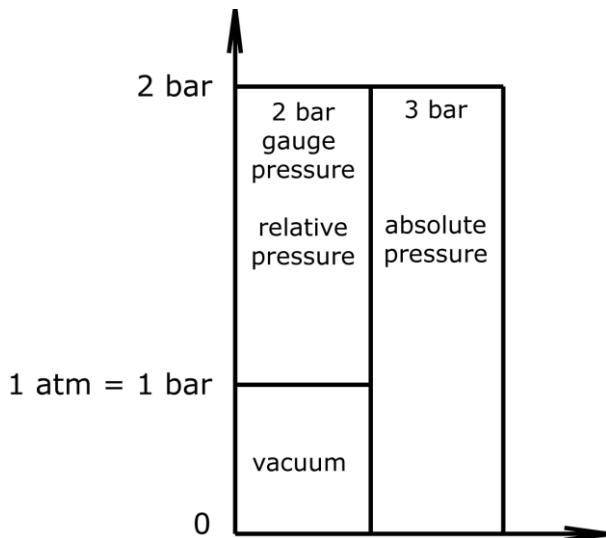
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In case **absolute pressure** is measured, standard atmospheric pressure is included. The scale starts at 0 Pa = total vacuum.

Absolute pressure = standard atmospheric pressure + gauge pressure (relative pressure)



Expressions:

- $P_{(a)}$: Absolute pressure
- $P_{(t)}$: Excess/Gauge pressure
- $-P_{(t)}$: Vacuum

Examples:

- 6 bar excess pressure = 6 bar_(t)
- 7 bar absolute pressure = 7 bar_(a)
- 0.7 bar absolute pressure = 0.7 bar_(a) or -0.3 bar_(t)

The expressions „excess pressure“ and „vacuum“ refer to a value larger or smaller than standard atmospheric pressure.

There are different **levels of vacuum**:

Standard atmospheric pressure	101325 Pa	= 1.01325 bar = 1 bar
Low vacuum (rough vacuum)	100 kPa ... 3 kPa	= 1 bar ... 0.03 bar
Medium vacuum	3 kPa ... 100 mPa	= 0.03 bar ... 0.001 mbar
High vacuum	100 mPa ... 1 μ Pa	= 0.001 mbar ... 0.01 nbar
Ultra-high vacuum	100 nPa ... 100 pPa	
Extremely high vacuum	< 100 pPa	
Outer space	100 μ Pa ... < 3 fPa	
Perfect vacuum	0 Pa	

In pneumatics we use the unit **bar** for vacuum as well as for excess pressure.

Unless there is any further indication, we normally work with **excess pressure = relative pressure**.

Chapter 1:

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In practice:

We will calculate the force of a cylinder with a defined diameter at a specific pressure.

According to Pascal's law:
$$p = \frac{F}{A}$$

- **p**: Pressure [Pascal]
- **F**: Force [N]
- **A**: Surface [m²]

How much force does a cylinder with a diameter of 40 mm apply at a pressure of 6 bar?

In order for us to use the correct units of measurement, we will use the unit Mpa for pressure. This conforms to N/mm². For the diameter we will use mm.

Diameter of the piston of the cylinder

d = 40 mm

The surface of the piston is to be calculated as a circular area:

$$A = \frac{d^2 \cdot \pi}{4}$$

In numbers:

$$A = \frac{d^2 \cdot \pi}{4} = \frac{40(\text{mm})^2 \cdot 3,14}{4} = 1256 \text{ mm}^2$$

At a (relative) working pressure p = 6 bar = 0.6 $\frac{\text{N}}{\text{mm}^2}$

Thus:

$$F = p \cdot A$$

In numbers:

$$F = p \cdot A = 0,6 \left(\frac{\text{N}}{\text{mm}^2} \right) \cdot 1256 (\text{mm}^2) = 753,6 \text{ N}$$

This is the theoretical force. In practice we have to take losses due to friction into consideration (approx. 5%).

Thus: A cylinder with a piston with the diameter of 40 mm at 6 bar pressure generates approx. **716 N force. This translates into the ability to lift approx. 73 kg.**

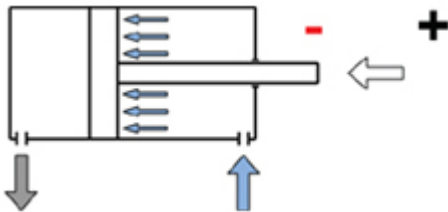
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How much force does the same cylinder generate into the opposite direction (pulling its rod back in)?

Due to the piston rod itself, the surface to push the rod out is larger than the surface to pull it back in. The missing surface has to be deducted.



D = diameter of piston (40 mm)

d = diameter of piston rod (16 mm)

$$F = p \cdot A = p \cdot \left(\frac{D^2 \cdot \pi}{4} - \frac{d^2 \cdot \pi}{4} \right) = 0,6 \left(\frac{N}{mm^2} \right) \cdot \left(\frac{40(mm)^2 \cdot 3,14}{4} - \frac{16(mm)^2 \cdot 3,14}{4} \right)$$

$$F = 0,6 \left(\frac{N}{mm^2} \right) \cdot 1055,04(mm^2) = 633,024 N$$

After deducting 5% as loss for friction we find that **the pulling force** of the same **cylinder is approx.**

601 N, in comparison to the 716 N **pushing force**.

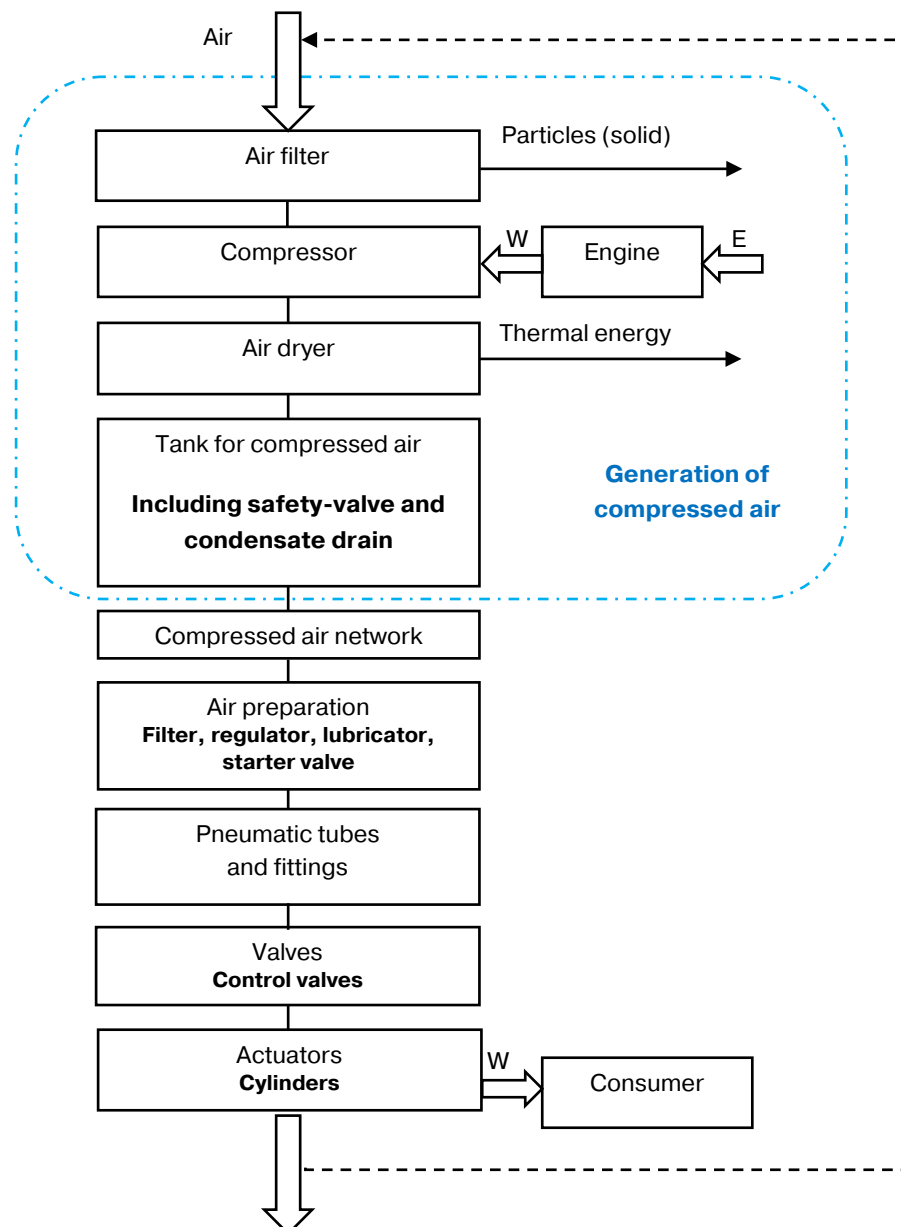
Chapter 2:

The General Design of a Pneumatic System and its Components

The route of compressed air from its generation to the consumer

In **pneumatics compressed air is utilized for performing mechanical work and for control**. In order to do so we need different equipment to generate, treat and handle compressed air.

The graph displays the route of the environmental air from the compressor to the consumer of compressed air:



When designing a pneumatic system, typically the individual elements are distributed spatially depending on their task. Although they are spatially separated, **they are still connected systematically**.

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Generation and transportation of compressed air

We will have a brief look at the following elements of pneumatic systems.

Air filter

The air filter is integrated into the intake of the compressor. It prevents large, polluting particles on the outside from entering the air system. Through filtration, a major portion of unwanted particles can be kept out of the system.

Compressor

The task of the compressor is to compress the air to the required pressure and in the required volume. The engine consumes energy. The compressor transforms this energy and stores it as compressed air. Unfortunately losses are severe. The screw compressor is the most common type. Piston compressors are used as well.

Air Dryer and Pre-Filters

When air is compressed it loses its ability to hold water. Therefore water remains when air is compressed. As this water, the condensate, would be disturbing the following processes, it needs to be removed from the pneumatic system. In a so called refrigeration dryer the water condensates and can be removed. There are also absorption dryers in which the water is absorbed by special materials.

The compressed air is also regularly polluted by oil from the compressor or particles that have not been caught by its intake filter. Those can cause problems in the pneumatic system, e.g. in the valves. Often times they are separated from the compressed air by using a central filter unit.

We will cover air preparation in a later chapter of the course in detail.

Tanks

Tanks are used for storing compressed air temporarily. The storage guarantees that the demand can be covered securely. Often times you can find a condensate drain at the tank. The condensate can then drain off through a valve. The drain is actuated manually or automatically.

Compressed Air Network

The task of the network is to distribute the compressed air from the compressor to the user(s). The size of its tubes is important because it has a significant influence on the security of supply.

In general:

- The longer the tubes the bigger the loss of pressure due to friction.
- The more users are connected the bigger the orifice of the tubes needs to be.

The Quality of Compressed Air

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The operational safety of an air system is directly linked to the quality of the compressed air.

In general:

- A „better“ = cleaner air increases the operational safety of the system as the risk of blockage and wear is reduced.
- Please take into consideration that the manufacturers of the components and devices communicate the quality requirements for the air in use. Air quality is standardized by **ISO 8573-1:2010**.

Contaminants and purity classes – the standard ISO 8573-1

Particles, oil and water are the most important contaminants in compressed air. For each of these three there are purity classes in the standard.

ISO 8573-1:2010							
Class	Particles				Water		Oil
	Maximum number of particles of the following size [µm] / m³ of compressed air			Concentration	Pressure dew point °C	Content of liquid [g/m³]	Total content (liquid, aerosol, gas) [mg/m³]
	0,1 ... 0,5 µm	0,5 ... 1 µm	1 ... 5 µm	[mg/m³]			
0.	By definition of the user, less contamination than class 1						
1.	≤ 20 000	≤ 400	≤ 10	-	≤ -70	-	≤ 0,01
2.	≤ 400 000	≤ 6000	≤ 100	-	≤ -40	-	≤ 0,1
3.	-	≤ 90 000	≤ 1000	-	≤ -20	-	≤ 1
4.	-	-	≤ 10 000	-	≤ +3	-	≤ 5
5.	-	-	≤ 100 000	-	≤ +7	-	-
6.	-	-	-	≤ 5	≤ +10	-	-
7.	-	-	-	5 ... 10	-	≤ 0,5	-
8.	-	-	-	-	-	0,5 ... 5	-
9.	-	-	-	-	-	5 ... 10	-
X	-	-	-	> 10	-	> 10	> 5

Purity classes in accordance to standard ISO 8573-1

For example: ISO 8573-1:2010 [4:3:3]

Particles = class 4, water = class 3, oil = class 3

High quality compressed air is (by definition) 100% oil free = class 0. Air of this quality is required in medical applications, the food-industry and electronic industry.

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Let's not forget air pollution!

When designing a compressed air system take environmental factors into consideration! **Air pollution** is concentrated when the air is compressed. Industries with high emissions in the neighbourhood can be of severe impact. Other factors such as a high concentration of ozone can influence your system and eventually harm seal materials as well. Never ignore climatic conditions. The dryer has to be more capable in a hot and humid environment.

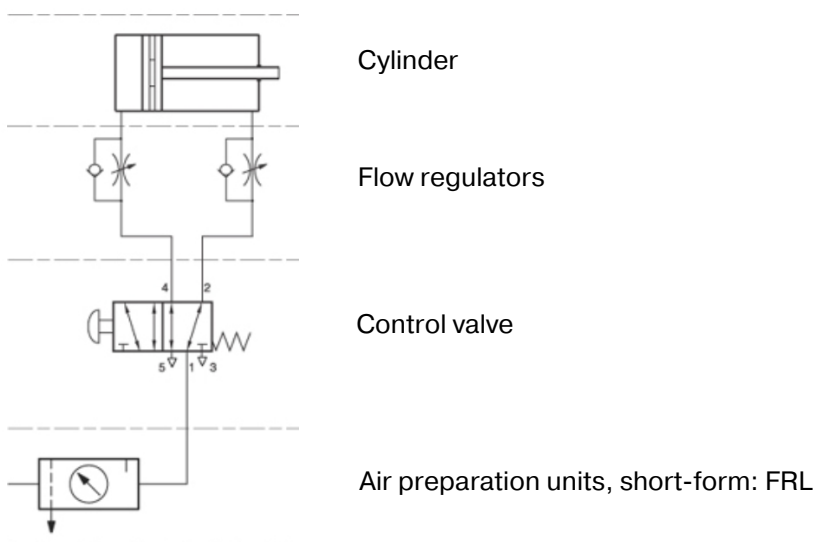
Therefore it is important that...

- we know what kind of air is sucked into our compressor
- we make sure that after compressing the air is dried, cleaned and potential oil is separated from it
- we consider the influence of the environmental factors (climate and pollution)
- components with very high loads are lubricated where necessary

.. in order to guarantee a safe operation.

The most important elements at the machine-level

The sketch exemplifies a pneumatic system at the machine-level:



The individual elements are represented by **ISO-symbols**, which are connected with lines. They display the **route of the compressed air**. In order to get a better overview we position the air preparation on the bottom and the actuators on the top of the drawing.

We can form logic groups of the elements – as you can see in the drawing above:

- **Air preparation**

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The General Design of a Pneumatic System and its Components



- Filter
- Pressure regulator
- Lubricator
- Switch-on valve
- Soft start
- ...

Control valves

- Directional control valves
- Other types of control valves
- Logic elements
- ...

Flow control valves, check-valves

- Flow control valves, uni- or bidirectional
- Exhaust flow-regulators
- Non-return valves = check valves
- Function fittings
- ...

• Actuators, cylinders

- Cylinders
- Rodless cylinders
- Rotary actuators
- ...

• Tubes and fittings

- To distribute compressed air and to connect different components

Hafner-Pneumatik distributes its products under the following **groups and categories**:

- HAFNER Valves



Chapter 2:

The General Design of a Pneumatic System and its Components

- Cylinders



- Process Valves



- Air Preparation Units



- Fittings



- Tubes



We will study the function of all these groups in later chapters.

Chapter 3:

Grouping and construction of control valves



Pneumatic valves control **pneumatic actuators** such as cylinders, rotary actuators etc. The valves control the **direction**, **speed** (by flow) and **force** (by pressure) of the actuator.

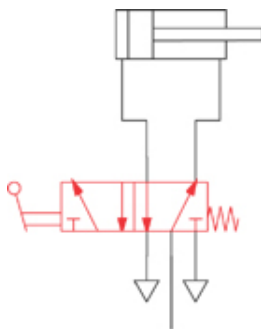
We can form the following groups of valves by distinguishing between their functions:

The ISO-symbol tells you a valve's function. By "reading" the symbol correctly you get hints of how to use it.

- **Control of the effective direction of actuators** – Directional control valves

These valves control the actuators directly or they control other control valves.

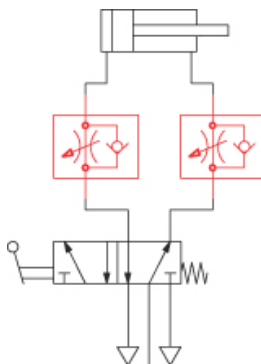
Application example: Control of a double acting cylinder by a 5/2-way hand-lever valve:



- **Control of the amount of compressed air into / out of the actuator** – Flow regulators

These valves limit the amount of air flowing through them.

Application example: We can add two **uni-directional flow regulators** to the example above. They control the speed of the cylinder by limiting the amount of air that is exhausted from it. Limiting the exhaust air is generally the better way in comparison to limiting the air-supply, since it results in a smoother movement of the piston.



- **Pressure regulation** – Pressure regulators

Chapter 3:

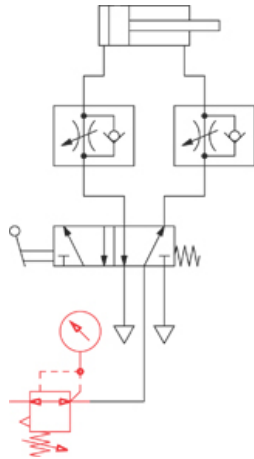
Grouping and construction of control valves



These products keep the secondary pressure at a distinct level when the incoming pressure is volatile. As you know from Chapter 1, pressure determines the force of an actuator.

Please note: The secondary pressure can only go as high as the entry pressure.

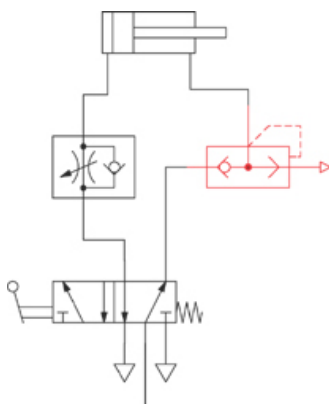
Application example: We can add a **pressure regulator** to the example above. That way we can control the maximum force of the cylinder by regulating the maximum pressure of the system behind the pressure regulator. A pressure gauge indicates the secondary pressure.



- **Quick exhaust** – Quick exhaust valves

These valves are designed to exhaust the air from an actuator quickly, which increases the speed of the piston.

Application example: We can replace one of the flow-regulators with a quick exhaust valve in the example above. By doing so, the air in the chamber of the cylinder exhausts directly into the environment and the air does not flow back through the control valve. This maximizes the push-speed of the piston.



- **Logic elements**

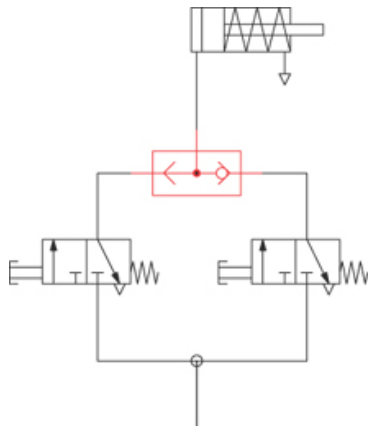
Chapter 3:

Grouping and construction of control valves



These valves are not used for directly controlling actuators but to set up pneumatic control systems. Typical elements are: AND, OR, YES, NO. With these functions taken from the Boolean algebra, most (mathematical) problems can be solved.

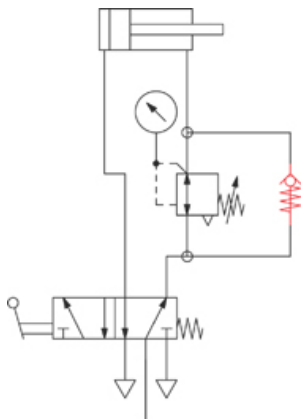
Application example: A single acting cylinder has to be controlled by either one **OR** the other of two 3/2-way valves. In case you want to make sure that the cylinder only moves if **BOTH** 3/2-way valves are actuated, replace the OR-gate by an **AND**-gate.



- **Non-return valves = Check valves**

Check valves provide a free flow into only one direction. If compressed air comes from the opposite side, it is blocked.

Application example: In order to save compressed air on a double acting cylinder that is „doing work“ in only one direction, the air-pressure that is needed to return the piston can be reduced significantly. A second pressure regulator is required for that. This regulator has to have a by-pass when the air exhausts from the relevant cylinder-side. The “one-way” by-pass is realized by using a check-valve.



A typical application of a check-valve is the combination with a flow-regulator (see above example). This product is called Uni-directional flow regulator. In one direction the air can by-pass the regulator, whereas in the other direction the free flow is blocked and the air is forced to go through the regulator.

General information on directional control valves

Directional control valves are the most important elements of a pneumatic control system.

Chapter 3:

Grouping and construction of control valves



In any fluid application they are utilized to define the route of the medium. They are used to control cylinders or other actuators. They can also control the movement and the direction of pneumatic motors or control other control valves.

Directional control valves are not designed for regulating pressure or flow.

We can form categories of directional control valves as follows:

- By basic design
 - Spool valves
 - Poppet valves

- By actuation
 - Mechanically actuated
 - Manually actuated
 - Pneumatically actuated
 - Electrically actuated (solenoid valves)

- By the number of **(stable) positions**
 - One stable position: single solenoid / single pilot valve or spring return valve.
 - Two stable positions: double solenoid / pilot valve, lever valve indexed.
 - 3-positions valves.

- Flow in basic position
 - For **2/2-way and 3/2-way** valves with spring return
 - Normally open
 - Normally closed
 - For **3/3-, 4/3- and 5/3-way** valves
 - Centre closed
 - Centre exhausted
 - Centre pressurized

- By the number of ports / positions
 - **2/2-way** (2 ports, 2 positions)

Chapter 3:

Grouping and construction of control valves



- **3/2-way** (3 ports, 2 positions)
- 3/3-way (3 ports, 3 positions)
- 4/2-way (4 ports, 2 positions – only one exhaust port)
- **5/2-way** (5 ports, 2 positions)
- 4/3-way (4 ports, 3 positions – only one exhaust port)
- **5/3-way** (5 ports, 3 positions)

The most common types are in bold. Besides the ones mentioned above there are more possibilities for special applications (e.g. 5/4-way valves, 7/3-way valves, ...)

Basic design of directional control valves

Let's have a look at the basic difference between spool and poppet valves.

One of the basic elements of any directional control valve is the **valve body**. The body holds the parts of the valve together. The second important element is the moving part(s), which blocks and opens ports, or connects two or more of them with each other.

Chapter 3:

Grouping and construction of control valves



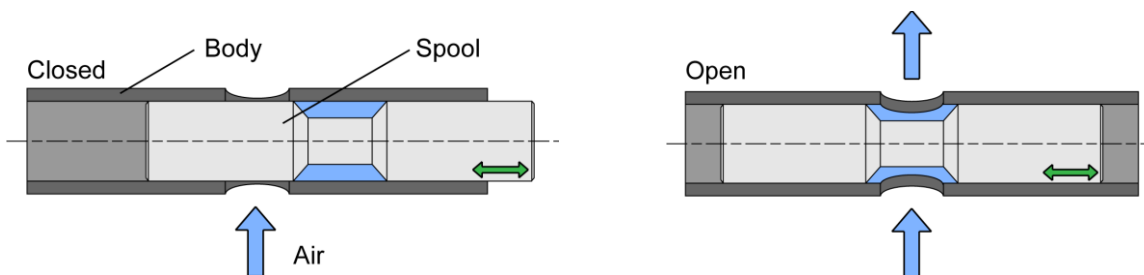
The closing element can either be a **spool** or a **valve disk**. Therefore we distinguish between:

- **Spool valves** and
- **Poppet valves.**

Spool valves

In spool-valves the different ports are connected by axially moving a cylindrical spool.

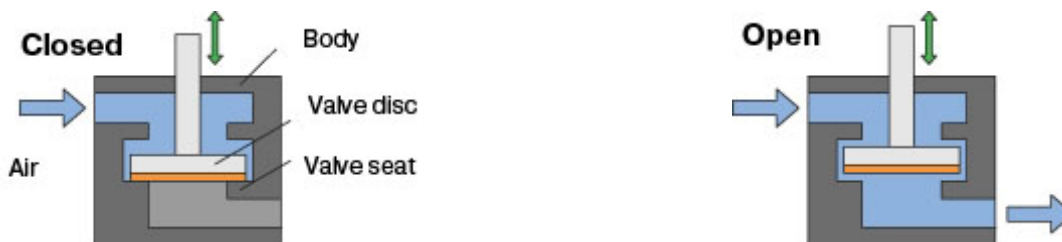
The drawings below display the closed and open position of a spool valve.



Poppet valves

In a poppet valve a valve-disc is pushed onto the valve-seat. When the disc is released again, the valve opens.

The drawings below display the closed and open position of a poppet valve.



Grouping directional control valves by modes of actuation

Actuation means the source of energy which moves the closing element (disc or spool):

- **mechanically** a part of a machine pushes onto a stem or a roller-lever of the valve
- **manually** a human being operates a knob or a lever
- **pneumatically** a pressure signal moves the spool or the disc

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Grouping and construction of control valves



- **electrically / solenoid** the plunger of a solenoid opens a poppet valve (lifts the disc on the seat)
- **solenoid pilot** the plunger of a solenoid opens a poppet valve, the moves a spool or a second (larger) disc.

Solenoid valves can be distinguished as:

- **Direct acting valves**

The (poppet) valve is directly opened by electric energy.

- **Piloted valves (solenoid pilot spool valves)**

The main valve is generally a spool valve. The spool is driven by compressed air. This pilot air is controlled by a poppet valve. Part of the energy used to control the valve is supplied by the medium.

The method of using the energy of the medium is not only used in spool valves. Poppet valves or diaphragm valves can be designed like that, too.

- **Solenoid valves with external pilot feed**

This function is very similar to the solenoid pilot valves. The difference is that it's not the energy of the medium of the main valve which is used to move the spool, but instead there is an additional port for compressed air. The solenoid system is separately supplied through that.

Valves are available with different numbers of (stable) positions:

- **One stable position**

As soon as the actuation is gone (i.e. the pneumatic signal or electric energy is cut, the button is released) the spool or the disc is forced back into its basic position. This movement can be powered either by a mechanical spring or by the energy of the medium ("air spring").

- **Two stable positions**

Whenever the actuation stops, the spool or disc stays in its current position until there is an actuation into the opposite direction.

Chapter 3:

Grouping and construction of control valves



- **3 positions valves**

The spool / disc can generate 3 different kinds of connections of the ports (very rarely more). Manually actuated valves can be designed with 3 stable positions or in a way that the spool is driven into centre position by mechanical springs. Valves that are actuated in other ways are normally only available with a basic position.

Description number of ports and number of positions:

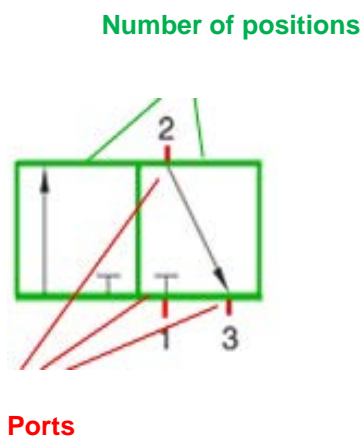
The following will only offer a first glance at this topic. You will receive more information in a later chapter.

The valve is called **X/Y-way** valve, where **X represents the number of ports** in the main valve and **Y the number of positions**.

Example:

3/2-way valve

The valve has **3 ports** and **2 positions**.



In Europe you will find mostly **2/2-**, **3/2-**, **5/2-** and **5/3-way valves**. In the USA 4/2 and 4/3-way valves are common.

Application examples, distinguishing between solenoid valves:



Direct acting solenoid valve (e.g.: MH 311 015)

Basic design: **poppet valve**

Control: **solenoid - direct acting**

Number of ports / positions: **3/2-way**

Stable position(s): **one, single solenoid**

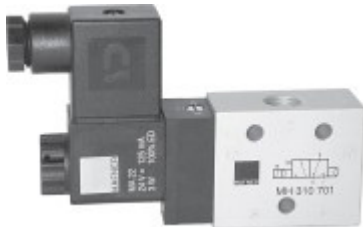
Basic position: **normally closed**

The electric energy consumed by the coil is directly used to open the valve disc.

Solenoid-pilot valve (e.g.: MH 310 701)

Chapter 3:

Grouping and construction of control valves



Although there are basically 2 valves inside this product - the main valve and the pilot valve -, the characteristics of the main valve define the product.

Basic design: Main valve = **spool valve**
Pilot valve = poppet valve

Control: **solenoid-pilot**
Number of ports / positions: 3/2-way
Stable position(s): **one, single solenoid**
Basic position: **normally closed**

The electric energy consumed by the coil is used to operate the plunger in the pilot valve. The energy for the main valve is given by the medium.

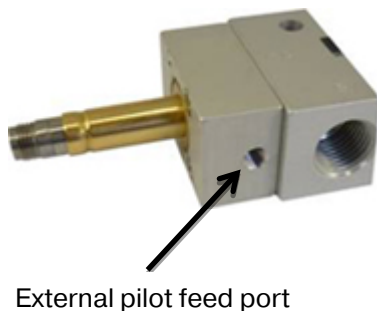
Solenoid valve with external pilot feed (e.g.: MEH 311 701)

There are 2 valves inside this product as well.
Once again the characteristics of the main valve define the product:

Main valve = **spool valve**
Pilot valve = poppet valve

Control: **solenoid-pilot**
Number of ports / positions: 3/2-way
Stable position(s): **one, single solenoid**
Basic position: **normally closed**

The electric energy consumed by the coil is used to operate the plunger in the pilot valve. The energy for the main valve is fed into the valve through an additional port in its head. Therefore the operation of the spool is independent from the medium's pressure applied to the main valve



External pilot feed port

Chapter 4:

Structure and function of directional valves

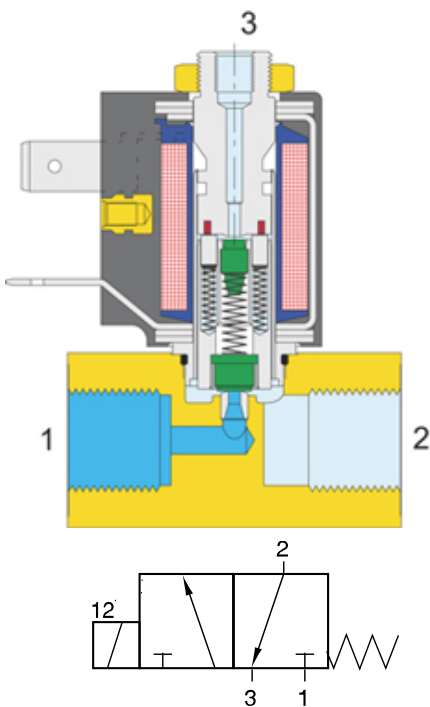


Structure and function of directional valves

1. Structure of direct acting solenoid valves

Direct acting solenoid valves are typically **poppet valves**. The movement of the valve disk opens and closes the route of the medium.

The graphic below shows the cross section of an electrically actuated direct acting 3/2-way valve.



Actuation: electrically (solenoid valve)

The electric current generates a magnetic field which is used to lift the plunger in the operator tube. Without current the plunger is pushed down by a mechanic spring. In a 3-way valve the plunger has two seals = valve discs, one on the bottom and one on the top. They are marked in green.

Control type: direct acting

The force of the magnetic field is used to open the valve. There is no other source of energy, including the medium.

Stable positions: one

The valve has one stable position defined by the mechanic spring holding the plunger. When the electric signal is applied the valve switches. Once it is absent, the valve switches back.

Basic position: normally closed

Without electric energy the media is blocked at port 1, thus the valve is closed.

Number of ports and positions: 3/2-way

The valve has 3 ports and 2 positions.

Typical features of direct acting valves:

- Orifice size: **DN 1,2 ... 3 mm**
- Operating pressure: **PN up to 10 bar**
- Nominal flow: **QN 10 ... 210 l/min**
- Port sizes: **M5, G1/8" and G1/4"**
- Power consumption: **3W / 5VA and more**



This type of valve offers a small orifice size at 10 bar. Therefore the flow is relatively low. If a larger orifice size is required, the power consumption increases at the same rate.

Function:

Chapter 4:

Structure and function of directional valves



Pressure supply is connected to port 1. The force of the spring pushes the valve disk onto the seat and closes port 1. This force has to be larger than the force of the medium. In basic position the valve is open from port 2 to 3. (This is the normal basic position of a 3/2 way normally closed valve.)

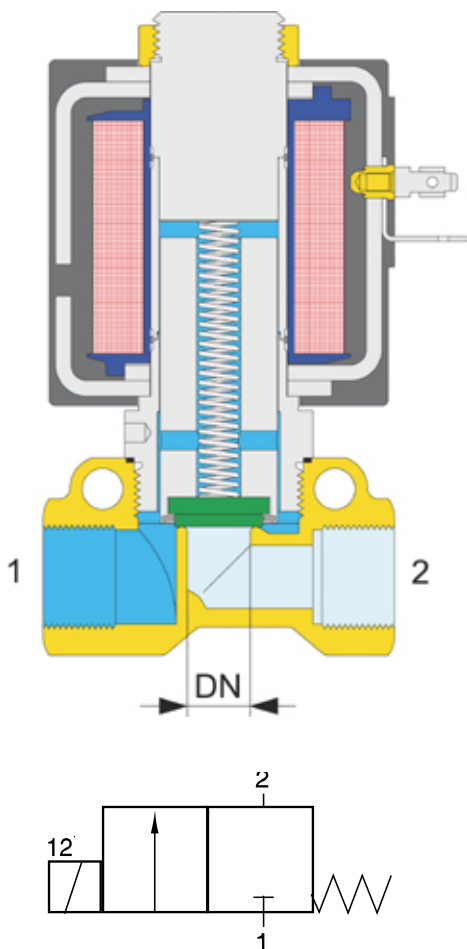
As soon as sufficient electric current is applied to the coil the valve disc is lifted from the valve seat of port 1. Simultaneously a second valve disc closes the seat between ports 2 and 3. Therefore the medium is free to flow between 1 and 2. The route between 2 and 3 is blocked.

As soon as the electric current is absent, the valve switches back into basic position (1 closed, open from 2 to 3).

Important! Direct acting solenoid valves only use the electric energy provided to lift the plunger against the force of the mechanic spring. Therefore this type is mainly used for valves with smaller orifice size. The force of the spring has to be larger than the force of the medium below the seat and the generated force of the coil larger than the one of the spring.

How are direct acting valves with larger orifice sizes designed?

The graph below shows the cross section of an electrically actuated direct acting 2/2-way valve.



The technical characteristics of this valve with large orifice size are:

- Operating pressure (max): **PN 2,5 bar**
- Nominal flow: **QN 1.670 l/min**
- Port size: **G3/8" and G1/2"**
- Power consumption: **16W / 20VA**
- Orifice size: **DN 10 mm**



The power consumption of this valve is 16W/20VA, which is relatively high. The heat emission will be significant so the coil needs to be large.

In order to overcome the mechanics explained above:

“The larger the orifice (DN) or the required pressure range, the stronger the spring needs to be in order to close the seat” the design here is different:

Pressure is not applied below the plunger but at the top. Therefore the valve can work with a softer (weaker) spring supported by the force of the medium. The applied electric force needs to overcome these 2 forces (spring plus medium) in order to open the valve. As mentioned above the required amount of electric energy is significant.

We learn from this example that if valves with a large orifice used at high pressure are required, we need to use a second source of energy. This energy is typically coming from the medium.

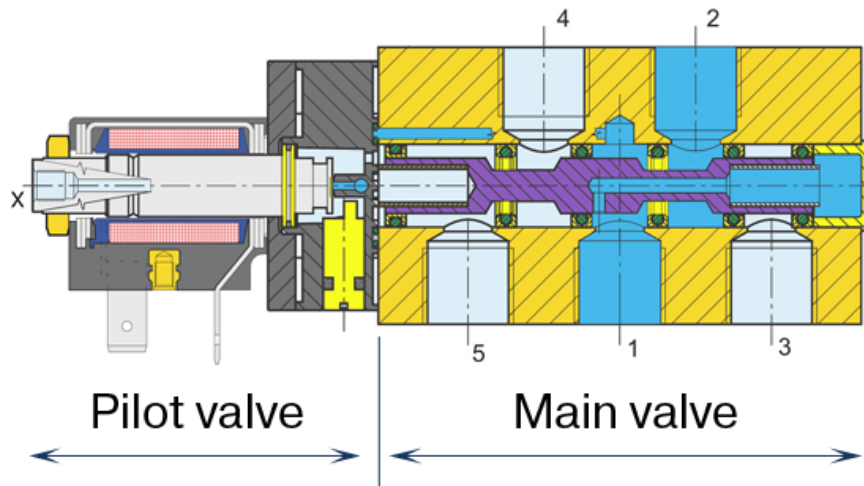
2. Structure of pilot operated spool valves

Chapter 4:

Structure and function of directional valves



Pilot operated valves (spool valves) consist of 2 parts. The graphic below shows the cross section of a 5/2-way single solenoid valve.



The pilot valve is a 3/2-way poppet valve.

The main valve is a 5/2-way spool valve.

The characteristics of the main valve are:

Basic design: spool valve

The axial movement of the spool opens and closes the route between distinct ports in the valve. This movement is provided by the energy of the compressed air.

Actuation: electrically (solenoid valve)

The pilot valve is electrically actuated. For its function see the explanation above.

Control: piloted

The pilot valve controls the pilot air which is taken from port 1 of the main valve and internally supplied to the pilot valve. Port 2 of the pilot valve is connected to the top of the spool, triggering its movement.

Number of stable positions: one

The valve has one stable position. As soon as the electric signal is absent, the pilot valve exhausts and the spool is pushed into basic position by either a mechanic spring or the force of the medium feed from port 1 of the main valve to the back-end of the spool (called air spring). Sometimes a combination of both types of springs is used.

Basic position: Typically a 5/2-way valve is open from 1 to 2 and from 4 to 5. There is no such thing as "normally closed" or "normally open" for 5-way valves.

Number of ports and positions:

5/2, the valve has 5 ports and 2 positions.

The typical features of Hafner spool valves are:



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Structure and function of directional valves



- Orifice: **DN 3 ... 18 mm**
- Operating pressure: **PN 10 bar**
- Nominal flow: **QN 200 ... 6.000 l/min**
- Port size: **M5 ... G3/4"**
- Medium: **Compressed air**
- Power consumption: **3W / 5VA**

Spool valves can combine a high flow (large orifice size) at a significant maximum pressure (the standard is around 10 bar, can be larger on request) with a low power consumption. In order to function correctly, the valves require a **minimum pressure**. If there is less pressure applied to the valve, the spool might not move. In this case the friction is too high.

Overview of advantages and disadvantages:

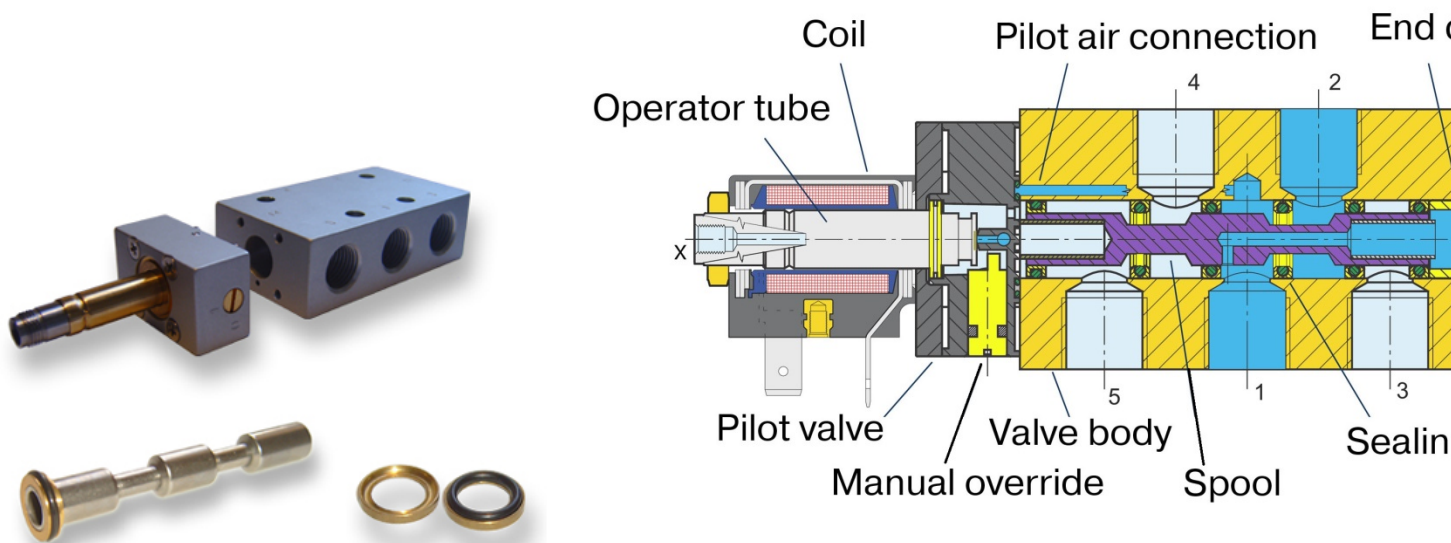
	Directly actuated valve Small orifice	Directly actuated valve Big orifice	Piloted valve Big orifice
Orifice / Flow	small	high	high
Max. Operating pressure	high	low	high
Min. Operating pressure	0	0	> 0
Power consumption	small	high	small

We will now introduce you to the **function** of 5-way solenoid spool valves which are pilot operated and explain the advantages of the Hafner design.

The graph below shows the cross section of a 5/2-way single solenoid pilot valve.

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Structure and function of directional valves



Function of a Hafner 5/2-way single solenoid valve (type: MH 510 / MD 510 / MMD 510)

Pressure is connected to port 1. Through an axial hole in the spool compressed air is fed towards one end of the spool into the end-cap (right side in the drawing), there the air spring is built up. The spool is pushed into basic position. (*Generally the valve can also be equipped with a mechanic spring*). Simultaneously the pilot valve is supplied with compressed air through the pilot air duct (indicated in blue).

The different sections inside the body of the main valve are separated by seals pressing onto the spool (green).

In basic position air is allowed to flow from 1 to 2. Besides that ports 4 and 5 (exhaust port) are connected. Port 3 is closed.

The main valve is piloted by a direct acting 3/2-way normally closed poppet valve that is supplied with air from the main valve. As the coil sitting on the operator tube is supplied with sufficient electric current the plunger is lifted. This opens the valve seat in the pilot valve and pilot air is fed to the "left side" of the spool. As the surface of the spool on that side is larger (approximately double) than on the spring side (right) the spool is moving towards the end cap.

Result: The main valve switches. Air connected to port 1 is now free to flow to port 4. Ports 2 and 3 are connected, 5 is closed.

When the current is taken away from the coil, the plunger drops and closing the seat in the pilot valve. Pilot air exhausts through the operator tube. The air spring becomes stronger than the opposite side of the spool and switches the main valve back into basic position.

Special features of Hafner valves with the "swimming O-ring".

By using high quality materials and modern means of manufacturing we can offer a range of products at high quality and with high reliability.

Materials in use – standard valves:

- **Body:** anodized aluminum

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Structure and function of directional valves



- **Spool:** Stainless steel
- **Operator system:** brass, stainless steel, FKM
- **Inner parts:** brass, POM, NBR
- **Seals:** NBR, FPM (FKM)

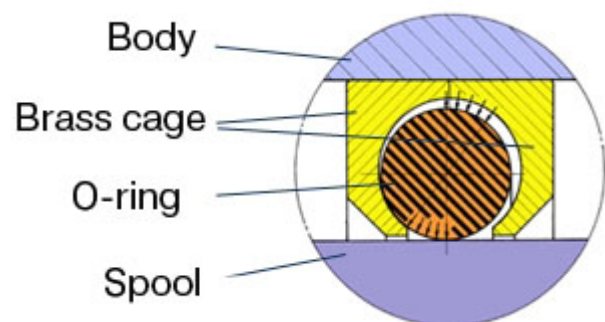
HAFNER also offers valves made from other materials or for specific applications such as:

- **Stainless steel** valves
- **Brass-free** products
- **Low temperature** valves (to -50°C)
- Poppet valves made from **polyamide**
- Valves for **explosion hazardous environments** (ATEX- approved)

Features of the sealing system with the „swimming O-ring“:

There is no deformation of the seal during assemblage of the valve - they are allowed to move independently within the brass cage. Without air pressure there is no contact pressure and, therefore, no friction. This construction also has consequences for the seals of the valves in use. When switching a 5/2-way valve only three of the five seals are exposed to pressure and applying friction to the spool.

- Because of the **low friction**, there is very little wear on the seals.
- As friction is low when pressure is low and friction as well as sealing effect increases with pressure **the valves switch safely at low as well as at high pressure.**
- Our customers benefit from **high durability** and **extended lifetime, high flow** combined with **compact design** as well as **high reliability.**



Communication of flow rates

The Hafner catalogue contains information about the flow-rates of the valves l/min (liter per minute).

The nominal flow is measured according to standard as follows:

Supply pressure $p_1=6$ bar, back pressure 5 bar

The flow of the air at $\Delta p=1$ bar is indicated after expanding the air from 5 to 0 bar in l/min.

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Structure and function of directional valves

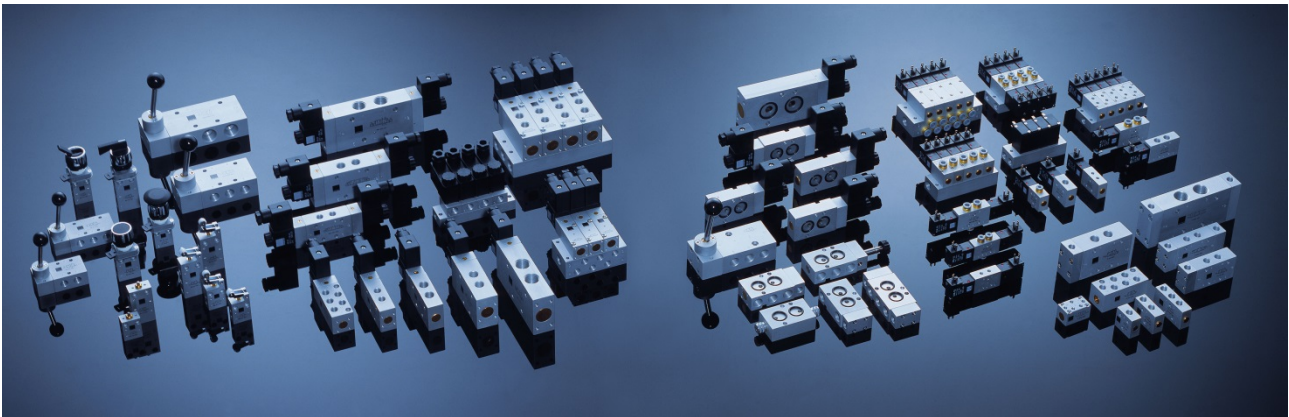


Therefore the amount of „expanded“ compressed air is 5 times the volume of the air that is actually flowing.

Important notice!

Some manufacturers communicate the „maximum flow“ at „maximum operating pressure“. This value might be significantly higher. In case you design your pneumatic system for significantly lower pressure than 6 bar you might want to use components with a bigger orifice.

HAFNER Pneumatik offers a very wide range of direct acting poppet valves and pilot operated spool valves with port size M5 to G 3/4" and a nominal flow of up to 6.000 l/min!



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ISO Schemes of directional control valves



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Schemes of directional valves

The description of directional valves is standardized by **DIN ISO 121**.

IMPORTANT! The ISO symbols display only the function of the valves. They do not give any further information about the design, flow, orifice size, etc.

Basics of the ISO symbols:

- Each position the valve can take is represented by a square.
- The number of squares tells you the number of positions the valve can take.
- The air pathways are represented by lines.
- The direction of the airflow is represented by an arrow.
- In case air flows in both directions there is a double arrow.
- Closed ports are displayed as a T.
- The ports carry numbers. The numbers are only shown in the square with the basic position of the valve.
- The type of actuation is also symbolized.
- The ISO-symbol contains information concerning the stability of the positions and the reset.

Directional valves – number of ports and positions

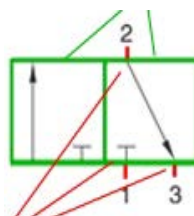
The directional valves are described by the numbers of ports in the main valve (excluding pilot ports) and the number of positions the valve can take, **[number of ports] / [number of positions]**

Number of positions

for example:

2 squares = 2 positions

3 ports



Number of ports

In this case we speak of a **3/2** way valve (spoken: three two way valve). Each position of the valve is displayed in a square. The basic position is symbolized by the numbers of the ports.

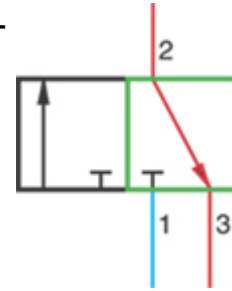
Chapter 5:

ISO Schemes of directional control valves



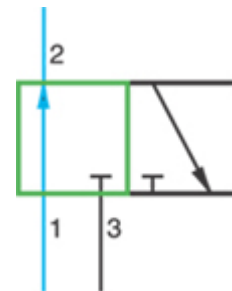
On the right hand side you can see the basic position of a normally closed 3/2-way valve.

- Port 1 = pressure supply is closed (blue).
- Port 2 = working, in basic position connected to port 3 = exhaust (red).
- Basic position or normal position drawn in green.



The second square displays the actuated position of the valve.

- Valve has been actuated (actuation elements not shown here).
- Port 1 is connected to working port 2 (blue).
- Exhaust port 3 is closed (black).
- Actuated position drawn in green.



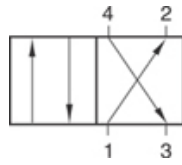
Symbols of the most common valves

2/2-way valve		Normally closed
		Normally open
3/2-way valve		Normally closed
		Normally open

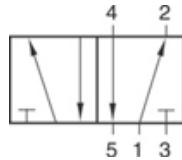
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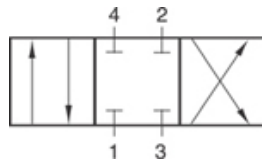
4/2-way valve



5/2-way valve

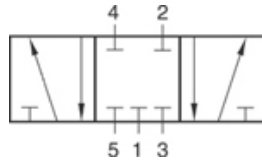


4/3-way valve



Center closed

5/3-way valve



Center closed

Symbols of actuation elements and resets

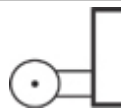
Apart from the squares showing the valve's function, the symbols for its actuation elements and elements to reset/return it are shown on the left, respectively right side of them.

Mechanically actuated,
Actuation by stem



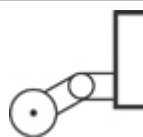
With spring reset

Mechanically actuated,
Actuation by roller lever



With air spring reset

Mechanically actuated,
Actuation by roller lever with idle
return



With combined (mechanical)
spring and air spring reset

Chapter 5:

ISO Schemes of directional control valves



Manually actuated,
Actuation with a push-button



Manually actuated,
Actuation by a lever



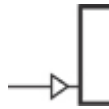
Manually actuated,
Actuation by a lever, indexed, 2 positions



Actuated by foot / foot valve



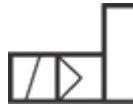
Pneumatically actuated



Electrically actuated,
Direct actuated valve



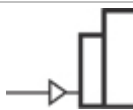
Electrically actuated,
Solenoid pilot valve



Manual override



Pneumatically actuated,
Differential piston, dominating side



Pneumatically actuated,
Differential piston.

Chapter 5:

ISO Schemes of directional control valves



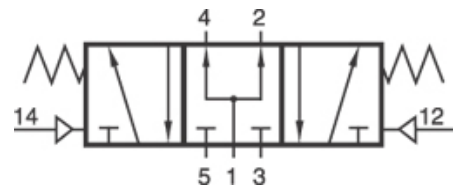
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Numbering of ports

All the ports in the valve are counted through. The numbers indicate the function of the port. The numbers always appear on the square for the valve's basic/normal position. In case we talk about a valve with 2 stable positions, the numbers are shown for the „implicit standard position“.

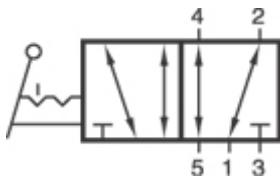
Basic position = normal position is the position the valve is in without actuation.

Pressure supply	1	P
Working port(s)	2, 4, (6)	A, B, C
Exhaust(s)	3, 5, 7	R, S, T
Pilot ports(s)	10, 12, 14	X, Y, Z



Examples:

The following lever- and pneumatically actuated valves allow airflow in both directions (double arrows).



- Actuation : **manually** (by a lever)
- 2 positions, both stable, indexed
- Number of pneumatic ports: **5**
- Thus: 5 ports, 2 positions = **5/2-way valve**

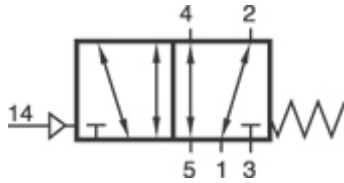
Manually actuated, 5/2-way valve, indexed

Type e.g.: **HVR 520 701**



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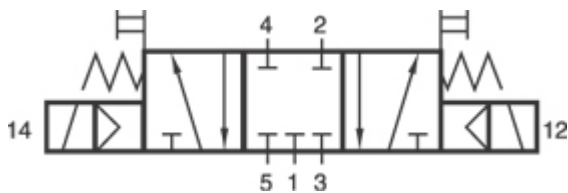
ISO Schemes of directional control valves



Pneumatically actuated 5/2-way valve, single pilot, mechanical spring reset

Type e.g.: **P 511 701**

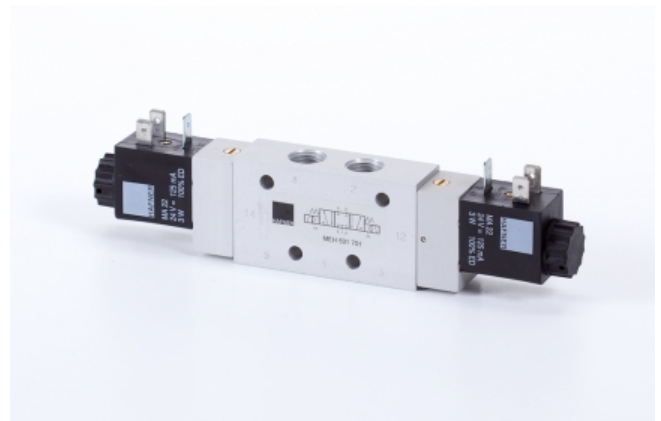
- Actuation : **pneumatically** (with air)
- 2 positions, one stable (with spring reset)
- Number of pneumatic ports: **5**
- plus pilot port 14
- Thus: 5 ports, 2 positions = **5/2-way valve**



Solenoid-pilot 5/3-way valve, 2 springs center the spool. Center position closed.

Type e.g.: **MH 531 701**

- Actuation : **electrically** (solenoid-pilot) including manual override.
- 3 positions, one stable (spring centered)
- Number of pneumatic ports: **5**
- Thus: 5 ports, 3 positions = **5/3-way valve**



Chapter 5:

ISO Schemes of directional control valves



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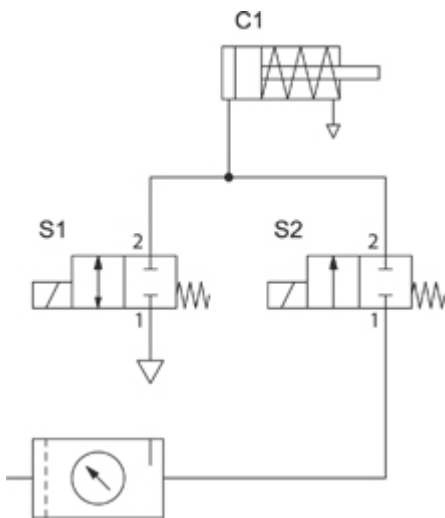
General information on circuits

Looking at the following circuits you can see potential ways for using different types of directional valves.

2/2-way valves

2/2-way valves are for opening and closing. They block the medium or let it pass. 2/2-way valves can be either normally closed or normally open.

In the scheme below two 2/2-way solenoid valves (S1 and S2) are used to control a cylinder with spring return (single acting) C1. Without actuation both solenoid valves are closed. In order to move the piston rod to the outer position (right) S2 has to be actuated. Compressed air is flowing from the source through S2 into the cylinder. In order to move the piston rod to the opposite position S2 needs to be de-energized and S1 has to be actuated. In case none of the valves are actuated, the piston rod stays in last position.



(The symbol at the bottom displays an FRL-unit (filter, regulator, lubricator). The functions of cylinders as well as of air-preparation units will be discussed in a later chapter.)

Chapter 5:

ISO Schemes of directional control valves



3/2-way valves

3/2-way valves are mostly used to control single acting actuators. They can be normally closed or normally open. In the scheme below you can see two applications.

1. An electrically actuated 3/2-way valve (S1) controls the single acting cylinder (C1).

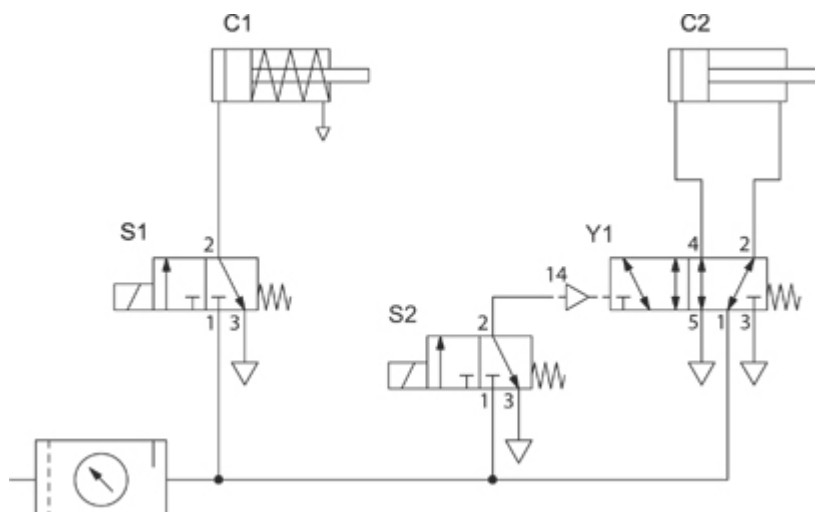
When the valve is actuated, air flows from 1 to 2; the piston rod of the cylinder is moving to outer position.

When the valve is de-energized, it switches back to normal position and the mechanic spring in the cylinder drives the piston rod back.

2. The double acting cylinder (C2) is controlled by a 5/2-way valve (Y1). Valve Y1 is controlled by an electrically actuated, normally closed 3/2-way valve (S2).

Valve S2 is actuated (air flows from port 1 to port 2). The air actuates valve Y1. It switches and air flows from port 1 to port 4; the piston rod of cylinder C2 moves to the outer position.

As soon as valve S2 is de-energized, air exhausts from port 2 to 3. Valve Y1 switches back into normal position because of the built-in mechanic spring. Compressed air in valve Y1 flows from 1 to 2 and the cylinder's exhaust from 4 to 5 as the piston rod moves back in.



Chapter 5:

ISO Schemes of directional control valves



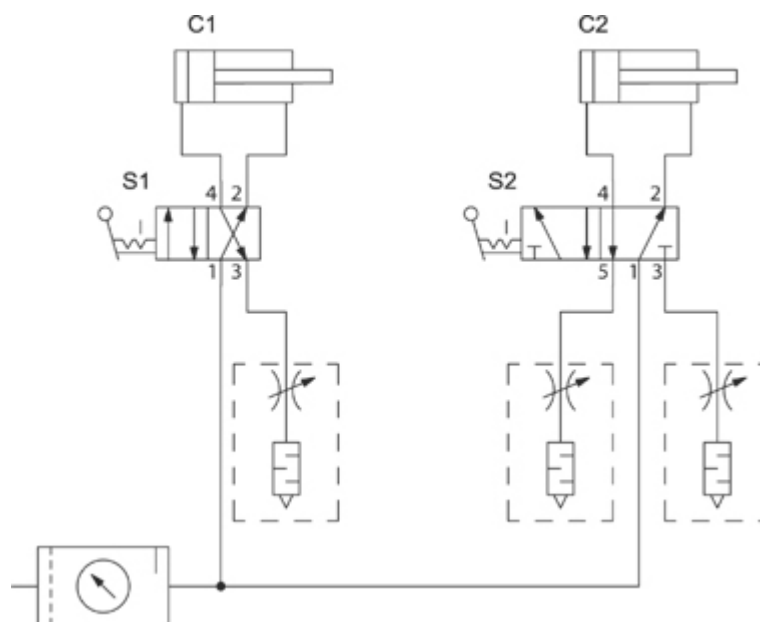
4/2-way and 5/2-way valves

4/2-way and 5/2-way, as well as 4/3-way and 5/3-way valves are usually used to control double acting actuators.

In the example below a manually actuated valve (S1 or S2) controls a double acting cylinder (C1 or C2). Additionally, in order to control the speed of the cylinder, flow control silencers are in use.

The major difference between the 4-way and the 5-way valve is that the 4-way valve offers only one exhaust port. Therefore the speed of the piston rod moving in or out cannot be controlled independently as the two chambers of cylinder C1 are exhausted through the same exhaust port 3 of valve S1.

As for the 5/2-way valve (S2), the two chambers on cylinder (C2) are exhausted through separate exhaust ports (5 and 3). This offers the possibility to regulate the speed of the piston rod **independently**.



Chapter 6:

Explanation of the Hafner type numbering system



Review of previous chapters

In the earlier chapters we introduced you to the most important characteristics of directional valves.

We have summarized them below:

Categorizing control valves by the following criteria ([chapter 3](#)):

- **Basic design**
(spool valve, poppet valve)
- **Actuation**
(mechanically, manually, pneumatically or electrically actuated valves)
- **Number of positions**
(2-, 3-, 4-, 5-way)
- **Number of ports (in combination with positions)**
(2/2-way, 3/2-way, 5/2-way, 5/3-way, ...)
- **Normal position**
(for 2/2- and 3/2-way valves: normally closed or open, for 5/3-way valves: center closed, exhausted, pressurized)

By design ([chapter 4](#)) we have to distinguish between poppet and spool valves. It is important to understand the difference in order to select the right valve for any application.

- **2/2- or 3/2-way** electrically and directly actuated poppet valves: directly controlled by the plunger of the solenoid system.
- **3- or 5-way** electrically actuated spool valves: controlled by an additional pilot-valve

Introduction to directional valves ([chapter 5](#)):

- **ISO symbols** and their meaning when it comes to function and positions
- **Numbering of their ports**

Chapter 6:

Explanation of the Hafner type numbering system



Explanation of the Hafner type numbering system

The HAFNER type numbers are a combination of letters and numbers, which carry further meaning. The most important characteristics of the valves are to be found in the type number.

The type number contains 3 major blocks (1-3)



To explain the system we use the valve type MH 510 701 G. This number has 3 main parts plus a suffix (block 4, variable).

The valve is defined by the 3 main blocks. The fourth block is there to indicate extra features, special materials etc.

... the fourth block indicates a special variation.



Although there are some exceptions, this standard covers most of the products.

Block 1 - actuation

The first letter defines **the mode of actuation** of the valve

Type



- **B** = Mechanically or manually actuated
- **H** = Hand lever valve
- **P** = Pneumatically actuated
- **M** = Solenoid valve

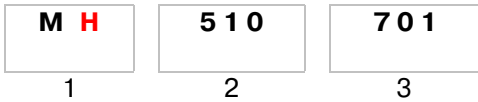
Chapter 6:

Explanation of the Hafner type numbering system



Type

The next letter(s) give further information



- **B** = Mechanically or manually actuated
 - **BV** = stem actuated valve
 - **BR** = roller lever valve
 - **BL** = roller lever valve with idle return
 - **BA** = stem valve with coupling for knob
 - **BH** = push-pull valve
- **H** = Hand lever valve
 - **HV** = with spring return (one stable position)
 - **HVR** = indexed
 - **HV(R)N** = valve-body with interface following NAMUR-standard
- **P** = Pneumatically actuated - no further information for standard products
 - **PN** = valve-body with NAMUR-interface
- **M** = Solenoid valve
 - **MH** = with manual override to turn, normally closed
 - **MD** = momentary manual override to push, normally closed
 - **MOH** = normally open MH valve (2/2 and 3/2-way)
 - **MOD** = normally open MD valve (2/2 and 3/2-way)
 - **MEH** / **MED** = with external pilot feed
 - **MEOH** = n.o. and with external pilot feed
 - **MK** = modified MH-valve, with solenoid MA16 (low power consumption 1.8W and for valve terminals)
 - **MNH** / **MND** = valve-body with NAMUR-interface
 - **MNOH** = valve-body with NAMUR-interface, normally open

This list is not limited to the types mentioned above, but only gives an overview about the most common products. There are many more.

Chapter 6:

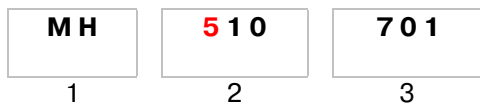
Explanation of the Hafner type numbering system



Block 2

The second block contains information about the number of ports, the number of stable positions and the type of spring.

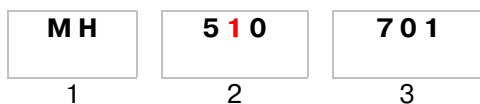
Number of ports in main valve



The first digit displays the number of ports.

- **2** = 2-way = 2 ports (2/2)
- **3** = 3-way = 3 ports (3/2 or 3/3)
- **5** = 5-way = 5 ports (5/2 or 5/3)

Positions



The second digit displays the number of positions and whether the valve has one or two stable positions.

- **1** = one stable position (single sol. / pilot)
- **2** = two stable positions (double sol. / pilot)
- **3** = 3-positions (_/3-way valves)

Return



In combination with the second digit (in this case "1"), the third digit informs about the type of spring:

- **10** = air spring (no *mechanic spring*)
- **11** = mechanic spring inside, can also be executed as a combination of an air- with a mechanic spring. At double solenoid valves the third number is always a "0" as they don't have any spring return.

Center position

for 3-position valves (e.g. MH 531 701)



In case we are talking about a 3-position valve, the third number defines the center position:

- **31** = Center closed
- **32** = Center exhausted
- **33** = Center pressurized

Chapter 6:

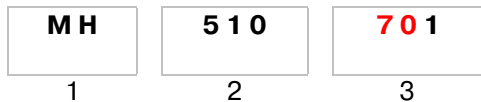
Explanation of the Hafner type numbering system



Block 3

Block 3 contains information about orifice size and ports.

Orifice size



Ports are BSP threaded by default.

NPT threads are to be indicated by a "NPT" suffix in block 4.

The second digit in block 3 defines the type of connection:

- **0** = tapped working ports 2 and 4
- **4** = 4 mm push-in fitting(s) in port(s) 2 and 4
- **6** = 6 mm push-in fitting(s) in port(s) 2 and 4

The first digit(s) represent the orifice and thread size.

- **20** = DN 2 mm, port: M5
- **30** = DN 3 mm, port: M5 or G1/8"
- **34** = DN 3 mm, 4 mm push-in fitting
- **40** = DN 4 mm, port: G1/8"
- **46** = DN 4 mm, 6 mm push-in fitting
- **50** = DN 5 mm, port: G1/8"
- **70** = DN 7 mm, port: G1/4"
- **80** = DN 8 mm, port: G1/4"
- **10** = DN 10 mm, port: G3/8"
- **12** = DN 12 mm, port: G1/2"
- **18** = DN 18 mm, port: G3/4"

The orifice size also lets us know about the flow:

- **20** = DN 2 mm, flow: 115 ... 125 l/min
- **30** = DN 3 mm, flow: 280 l/min
- **40** = DN 4 mm, flow: 450 l/min
- **50** = DN 5 mm, flow: 650 l/min
- **70** = DN 7 mm, flow: 1250 l/min
- **80** = DN 8 mm, flow 1450 l/min
- **10** = DN 10 mm, flow: 2250 l/min
- **12** = DN 12 mm, flow: 3000 l/min
- **18** = DN 18 mm, flow: 6000 l/min

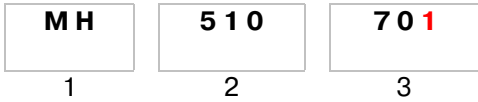
You can get more information about flow from the catalogue.

Chapter 6:

Explanation of the Hafner type numbering system



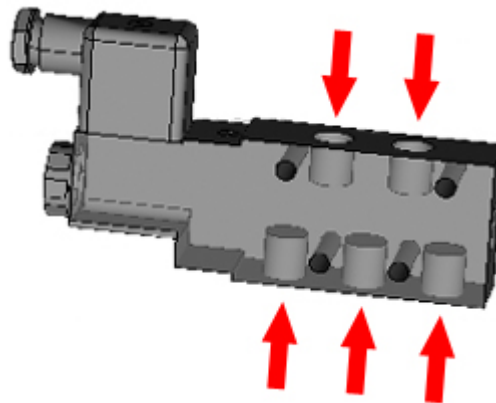
Position of ports



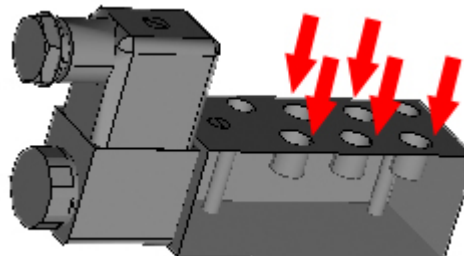
The last digit in block 3 defines the position of the ports within the body:

- **1** = Standard, ports on both sides of the valve
- **2** = All the ports on one side
- **3** = For manifold-plates only, supply and exhaust on one side, working ports on opposite side in the valve
- **4** = For manifold-plates only, all the ports are in the plate.

Standard (e.g. MH 510 701, MH 510 703)



All the ports on one side (e.g. MH 510 502, MH 510 704)



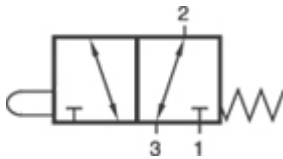
Chapter 6:

Explanation of the Hafner type numbering system



On the following four pages we explain some exemplary type numbers based on catalogue items:

BV 311 201



Block 1

Actuation: **BV**

- **B** = Mechanically actuated
- **V** = Stem

Block 2

- First digit: number of ports = **3**
- Second digit: number of (stable) positions = **1**
- Third digit: return = **1** = mechanic spring
 - ⇒ 3/2-way valve
 - ⇒ Mechanic spring return

Block 3

First and second digit: orifice size = **20** = orifice size 2 mm

Third digit: position of the ports = **1** = standard

- ⇒ M5 tapped ports (belongs to orifice size 2 mm)
- ⇒ Port 1 and 3 on one side, working port 2 on the opposite side.

Therefore the valve **BV 311 201** is a:

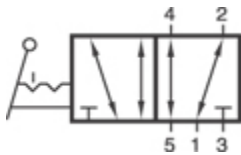
- Stem actuated valve
- 3/2-way with mechanic spring return
- M5-ports on both sides of the valve, orifice size 2 mm

Chapter 6:

Explanation of the Hafner type numbering system



HVR 520 701



Block 1

Actuation: **HVR**

- H = Hand lever valve
- VR = Indexed (without spring return)

Block 2

- First digit: number of ports = **5**
- Second digit: number of (stable) positions = **2**
- Third digit: return 0 = non = 2 stable positions
 - ⇒ 5/2-way valve
 - ⇒ 2 stable positions

Block 3

First and second digit: orifice size = **70** = orifice size 7 mm

Third digit: position of the ports = **1** = standard

- ⇒ G 1/4" tapped ports (belongs to orifice size 7 mm)
- ⇒ Ports 1, 3, 5 on one side, working ports 2, 4 on the opposite side.

Therefore the valve HVR 520 701 is a:

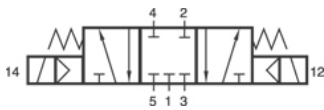
- Hand-lever valve
- 5/2-way indexed
- G 1/4" ports on both sides of the valve, orifice size 7 mm

Chapter 6:

Explanation of the Hafner type numbering system



MD 531 401 24 DC



Block 1

Actuation: **MD**

- M = Solenoid valve
- D = Manual override to push, momentary

Block 2

- First digit: number of ports = **5**
- Second digit: number of positions = **3**
- Third digit (if second one is a 3): center 1 = closed
 - ⇒ 5/3-way valve
 - ⇒ Center closed

Block 3

First and second digit: orifice size = **40** = orifice size 4 mm

Third digit: position of the ports = **1** = standard

- ⇒ G 1/8" tapped ports (belongs to orifice size 4 mm)
- ⇒ Ports 1, 3, 5 on one side, working ports 2, 4 on the opposite side.

Block 4

(Misc.) **24DC** for MD and MK valves only: voltage

Therefore the valve MD 531 401 24 DC is a:

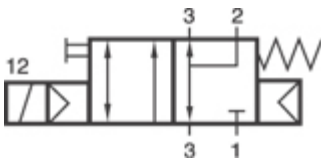
- Solenoid valve with manual override to push
- 5/3-way center closed
- G 1/8" ports on both sides of the valve, orifice size 4 mm
- Integrated solenoid 24V DC

Chapter 6:

Explanation of the Hafner type numbering system



MNH 311 701



Block 1

Actuation: **MNH**

- M = Solenoid valve
- N = NAMUR-interface
- H = Manual override to turn

Block 2

- First digit: number of ports = **3**
- Second digit: number of (stable) positions = **1**
- Third digit: return = **1** = mechanic spring inside (in this case a combined spring).
 - ⇒ 3/2-way valve
 - ⇒ Normally closed
 - ⇒ With combined mech.-pneum. spring

Block 3

First and second digit: orifice size = **70** = orifice size 7

Third digit: position of the ports = **1** = standard, in combination with the N in Block 1 with NAMUR-interface.

- ⇒ G 1/4" tapped ports (belongs to orifice size 7 mm)
- ⇒ Ports 1, 3, 5 on one side, working ports in accordance to NAMUR-standard (VDI/VDE 3845)

Therefore the valve MNH 311 701 is a:

- Solenoid valve with manual override to turn
- 3/2-way n.c.
- NAMUR-interface and ports 1, 3, 5 G 1/4, orifice size 7 mm

Chapter 6:

Explanation of the Hafner type numbering system



As you can see the HAFNER type numbering system is following a standard that allows you to understand what type of valve is in use or required whenever those numbers are mentioned.

An overview about the structure of the Hafner type numbers can also be found on page 16 and 17 in the valve catalogue 2016:

page 16

Type numbering system on the basis of MNH 510 701 24DC

Block 1 MNH		Block 2 510	
Actuation		Function	
M	Solenoid valve Without manual override	First number:	2 = 2-way, 3 = 3-way or 5 = 5-way valve
MMD	Solenoid valve with momentary manual override	Second number:	1 = actuation by permanent signal, 2 = actuated by impulse 3 = 3-way valves 53 = 5/3-way valves 33 = 3/3-way valves
MD	Solenoid valve with momentary manual override	Third number:	For 5/3-way and 3/3-way valves: 1 = middle position closed 2 = middle position exhausted 3 = middle position pressurized
MOD	Solenoid valve with momentary manual override	Other valves: 0 = pneumatic spring 1 = mechanical spring (MH-, MNH- and PN-valves have a combined spring)	
MH	Solenoid valve with bistable manual override	210	2/2-way Pneumatic spring return
MOH	Solenoid valve with bistable manual override	310	3/2-way Pneumatic spring return
MEH	Solenoid valve with bistable manual override	311	3/2-way Combined / mechanical spring return (depends on type)
MNH	Solenoid valve with bistable manual override	320	3/2-way Double solenoid
MNOH	Solenoid valve with bistable manual override	510	5/2-way Pneumatic spring return
MK	Solenoid valve with momentary manual override	511	5/2-way Combined / mechanical spring return (depends on type)
MNK	Solenoid valve with momentary manual override	520	5/2-way Double solenoid
P	Pneumatically actuated valve	531	5/3-way Centre closed
HV	Lever actuated valve with spring return	532	5/3-way Centre exhausted
HVR	Lever actuated valve indexed	533	5/3-way Centre pressurized
BV/BG	Stem actuated valve		
BZ	Stem actuated valve, actuation by pulling the stem		
BR	Roller lever valve		
BL	Roller lever valve with idle return		
BA	Valve for panel mounting		
BH	Push-pull button valve for panel mounting		
BHP	Push-pull button valve with pneumatic reset		
VA	OR-gate		
ES	AND-gate		
SE	Quick-exhaust valve		
DR	Flow regulator, uni-directional		
D	Flow regulator, bi-directional		
DRN	Flow regulator with NAMUR-interface		
UB	Air-recirculation block with NAMUR-interface		
SENR	Quick-Exhaust block with NAMUR-interface		
BHN	Block and block / block and bleed valves with NAMUR-interface		
Z/P	Plates for cylinder-valve combinations		
Z/PN	Various accessory plates		

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The Hafner valve type numbering system consists of at least 3 blocks.
Block 4 is to be used for voltage indication or special suffixes.
Please note: This overview is not intended to be exhaustive.

Block 3 701		Block 4 24DC	
Size & Position of Ports		Suffixes	
In-line valves:			
	Orifice size	Ports	Position of Ports
201	2 mm	M5	Standard
202	2 mm	M5	On one side
243	2 mm	Pf 4 mm	Side of valve
301	3 mm	G 1/8"	Standard
302	3 mm	M5	On one side
341	3 mm	Pf 4 mm	Standard
401	4 mm	G 1/8"	Standard
451	4 mm	Pf 6 mm	Standard
442	4 mm	Pf 4 mm	On one side
462	4 mm	Pf 6 mm	On one side
501	5 mm	G 1/8"	Standard
502	5 mm	G 1/8"	On one side
701	7 mm	G 1/4"	Standard
711	7 mm	G 1/4"	Ports swapped (NAMUR valves only)
801	8 mm	G 1/4"	Standard
101	10 mm	G 3/8"	Standard
121	12 mm	G 1/2"	Standard
181	18 mm	G 3/4"	Standard
Direct acting valves:			
	Orifice size	Ports	Position of Ports
010	1 mm	M5	Standard
012	1,2 mm	M5	Standard
015	1,2 mm	G 1/8"	Standard
305	3 mm	G 1/8"	Standard
309	3 mm	G 1/4"	Standard
014	1,2 mm	G 1/8"	Banjo-screw (port 2)
019	1,2 mm	G 1/8" - pif 6 mm	Banjo-screw (port 2)
013	1,2 mm	G 1/8"	Banjo-screw (port 2)
017	1,2 mm	G 1/8" - G 1/4"	Banjo-screw (port 2)
313	3 mm	G 1/8"	Banjo-screw (port 2)
317	3 mm	G 1/8" - G 1/4"	Banjo-screw (port 2)
Valves for manifold assembly:			
	Orifice size	Ports	Position of Ports
105	1,2 mm	G 1/4" - G 1/8"	Modular system, direct acting
239	3 mm	G 1/4"	Modular system, direct acting
339	3 mm	G 1/4"	Modular system, direct acting
304	3 mm	Flange for manifold	All on one side
503	5 mm	Flange for manifold	1,3,5 on one side as flange
504	5 mm	Flange for manifold	All on one side
703	7 mm	Flange for manifold	All on one side
704	7 mm	Flange for manifold	1,3,5 on one side as flange
104	10 mm	Flange for manifold	All on one side

Block 4 is to be used to indicate the voltage at solenoid valves or to give further information on special executions. Block 4 can consist of several suffixes.

Voltages	6VDC, 12VDC, 24VDC, 48DC, 24VAC, 110AC, 230AC
O.S.	without coil
NPT	NPT threads
IT	Low temperature
HT	High temperature
VES	Full stainless steel
KES	Stainless steel with PA pilot-head
G	Valves can be used in-line and also on manifold plates
Ex	ATEX-approved non-electrical valve
Exia	ATEX-approved for Ex ia coils
Ex m	ATEX-approved for Ex m coils
Ex nA	ATEX-approved for Ex nA coils
Ex mb	ATEX-approved for Ex mb coils
Ex dm	ATEX-approved for Ex dm coils
Ex d	ATEX-approved for Ex d coils
EDS	Brass-free to the outside
BMF	Entirely brass-free

Please note: Valves type "G" (e.g. 701 G) can be used as an in-line valve as well as for manifold assembly.

Chapter 7:

The pneumatic cylinder – part 1



In the earlier chapters we looked at the basic design of a pneumatic system and its most important elements:

- Air preparation
- Control valves
- Flow-regulators
- Actuators / cylinders
- Tubes and fittings

In this chapter we will be looking at **pneumatic cylinders**. **Cylinders are the most important means of actuation in pneumatics**. The cylinder transfers the energy that is stored in the compressed air into movement.

They can be classified by:

- **Design**
 - Cylinders with piston rods
 - Rodless cylinders
 - Diaphragm cylinders
 - Rotary cylinders
- **Movement**
 - Linear
 - Rotary = turning
- **Function**
 - Single-acting
 - Double-acting
 - 3- or 4-positions
- **Cushioning**
 - Adjustable, pneumatic cushioning
 - Flexible cushioning
 - Without cushioning

There is a very wide variety of pneumatic cylinders. In this training we will only focus the most common ones.

Cylinders with piston rods

Chapter 7:

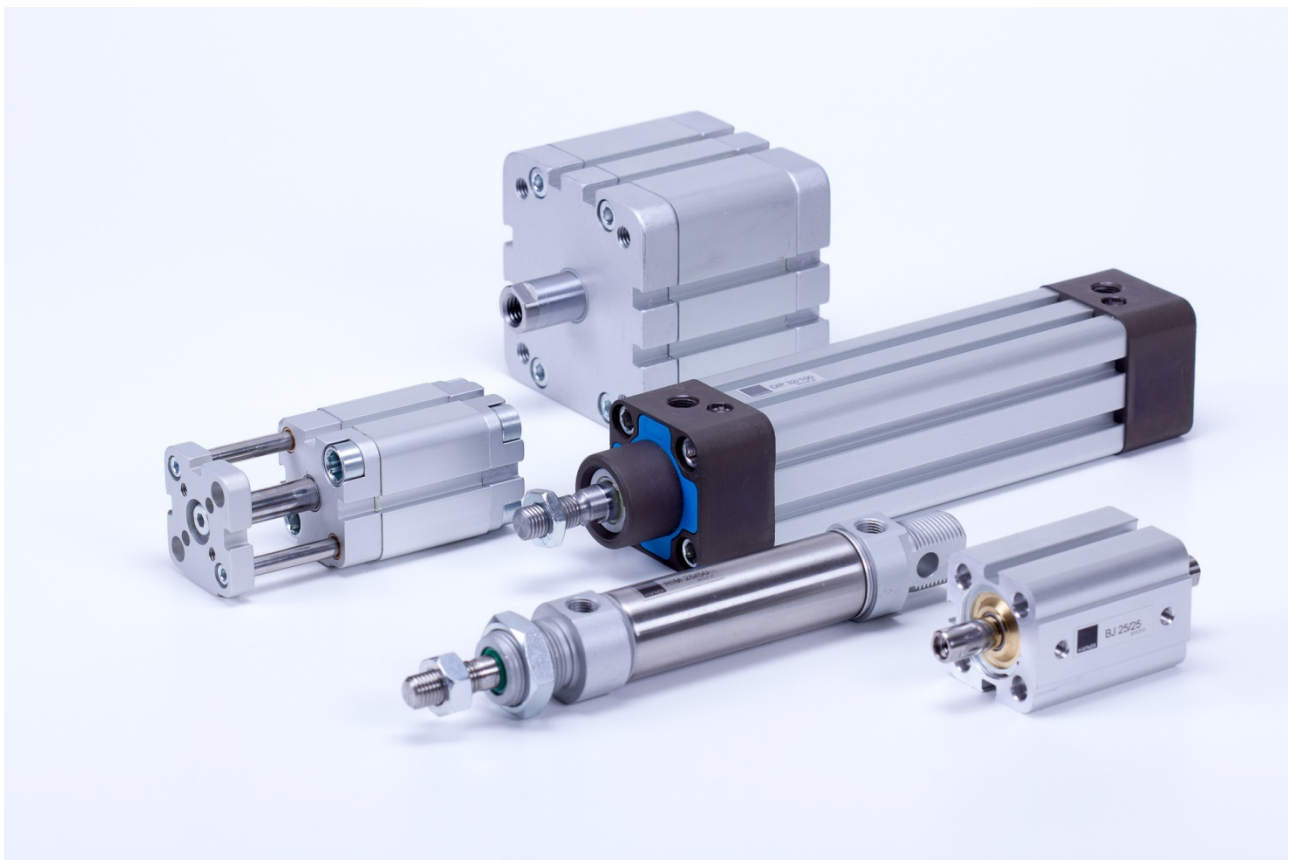
The pneumatic cylinder – part 1



Cylinders are available in different types and follow different international standards. Besides the ones that follow standards there are also “non-standardized cylinders”. Especially before the standardization into DIN/ ISO norms 6431 and 6432, there were numerous cylinder-types offered by different manufacturers.

Common standard cylinders are:

- Mini cartridge cylinders
- Round cylinders | DIN ISO 6432
- Profile cylinders | ISO 15552 | VDMA 24562 | (old norm: DIN ISO 6431)
- Compact cylinders | ISO 21287 | UNITOP
- Short stroke cylinders
- Tie rod cylinders | ISO 15552



Chapter 7:

The pneumatic cylinder – part 1

We will look at the following characteristics:

1. Design
2. Diameter and stroke
3. Movement
4. Number of positions
5. ISO symbols
6. Cushioning → chapter 8
7. Detection of cylinder position (magnetic) → chapter 8
8. Speed control → chapter 8
9. International Standards → chapter 8

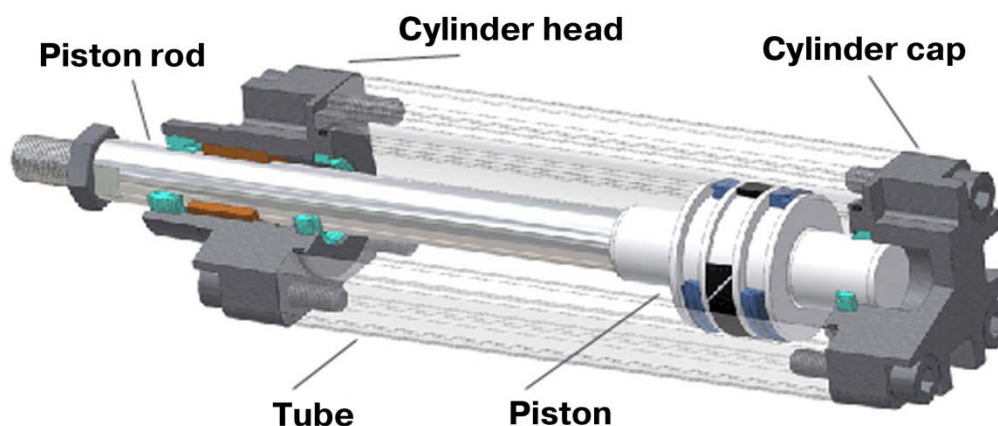
1. Design of a cylinder

Most of the cylinders with a piston rod contain the following parts: **a tube** that is closed **on both ends with a cap and head**. Inside the tube seen below a piston rod moves with a drive piston.

The movement of the piston is triggered by compressed air, controlled by a directional valve. The **direction** is defined by the chamber into which compressed air is allowed to flow inside the cylinder.

The force is transferred by the piston rod.

Components of a piston rod cylinder:



Chapter 7:

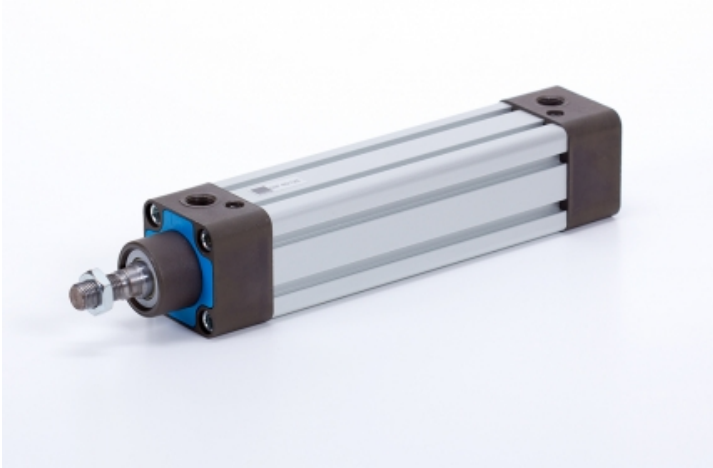
The pneumatic cylinder – part 1



2. Diameter and stroke

Diameter and stroke are the most important attributes of a cylinder.

e.g. HAFNER Cylinder DIP: **DIP 40/320**



Type numbering system:

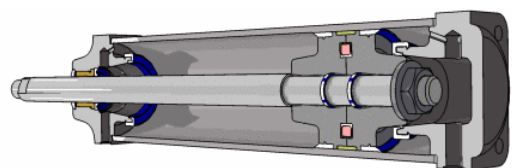
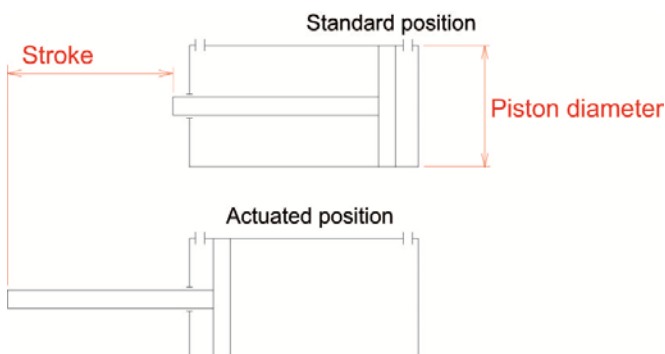
- **DIP** – type of cylinder / design

(DIP = ISO 15552 standard – double-acting cylinder – adjustable cushioning – magnetic piston)

- **40** – diameter of the piston [mm]
- **320** – stroke of the cylinder [mm]

The **diameter** is actually the diameter of the piston. The diameter of the cylinder defines its force relative to the air-pressure.

The **stroke** tells us how many millimetres the piston and therefore the piston rod can travel.



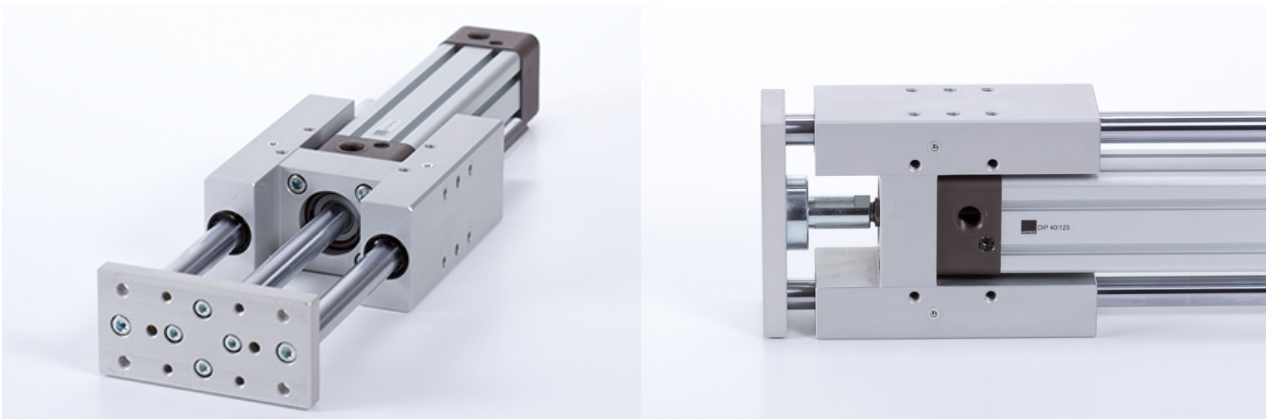
Chapter 7:

The pneumatic cylinder – part 1



If the stroke is long, the forces on the bearing between head and piston rod are high. In order to avoid a defect we recommend to select a larger diameter (cylinders with larger piston diameters also offer larger piston rod diameters).

In case of very long strokes or radial forces we recommend the use of a guide unit.



Pictures: DIP cylinder with assembled guide unit

Diameters and strokes are standardized, the most common values are:

Piston diameters [mm]:

| $\varnothing 8$ | $\varnothing 10$ | $\varnothing 12$ | $\varnothing 16$ | $\varnothing 20$ | $\varnothing 25$ | $\varnothing 32$ | $\varnothing 40$ | $\varnothing 50$ | $\varnothing 63$ | $\varnothing 80$ | $\varnothing 100$ | $\varnothing 125$ | $\varnothing 160$ | $\varnothing 200$ | $\varnothing 250$ | $\varnothing 320$ |

Stroke lengths [mm]:

| 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 100 | 125 | 160 | 200 | 250 | 320 | 400 | 500 | ...

The available diameters depend on, and are limited by, the type / standard. The availability of strokes on the other hand is less limited.

The maximum force generated by a cylinder depends on:

- **Operating pressure**
- **Diameter of the piston**
- **Friction of the inner parts**

As an example we calculate the force of a cylinder DIL 40/320 at 6 bar.

Chapter 7:

The pneumatic cylinder – part 1



Piston diameter:

$$d = 40 \text{ mm}$$

Surface of drive piston:

$$A = \frac{d^2 \cdot \pi}{4} = \frac{40(\text{mm})^2 \cdot 3,14}{4} = 1256 \text{ mm}^2$$

Operating pressure:

$$p = 6 \text{ bar} = 0,6 \frac{\text{N}}{\text{mm}^2}$$

Calculation of the force:

$$F = p \cdot A = 0,6 \left(\frac{\text{N}}{\text{mm}^2} \right) \cdot 1256 \text{ (mm}^2) = 753,6 \text{ N}$$

Thus we have a theoretical force of 753,6 N.

As a rule of thumb we can deduct 5% for friction. Therefore a cylinder with a piston diameter of 40 mm, and an operating pressure of 6 bar, **can exert a force of approx. 716 N.**

$$\frac{716 \left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2} \right)}{9,81 \left(\frac{\text{m}}{\text{s}^2} \right)} = 72,98 \text{ kg}$$

If we divide the force by gravity (9,81 m/s²), we find - in practice - that our cylinder can hold a mass of about 73 kg.

CAUTION! We can only hold the weight with this force, we cannot move it yet!

If we want to move a weight we have to (again) take gravity into consideration. Only then our cylinder is not only able to hold a weight but to perform work.

Chapter 7:

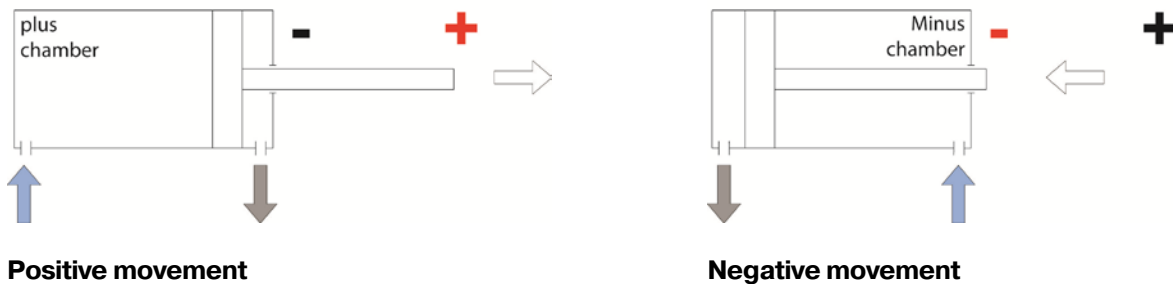
The pneumatic cylinder – part 1



3. The Movement of a cylinder

We call the two end-positions of a cylinder **positive / plus** and **negative / minus** positions.

Therefore we also call the two chambers inside the cylinder the plus and the minus chamber.



The position where the piston rod is out of the cylinder the furthest possible is called the **plus end-position**. In order to reach it, the **plus chamber** needs to be inflated.

The **minus end-position** is positioned on the opposite side; **the minus chamber** needs to be inflated.

The cylinder cannot reach an end-position if the opposite chamber is not fully exhausted!

4. Stable positions of a cylinder

We distinguish between **single-acting and double-acting** cylinders.

In **single-acting cylinders** only one chamber is inflated with compressed air. Therefore work is performed only in one direction by compressed air. For the movement into the opposite direction a **mechanic spring** is the source of energy. The stroke is limited by the length of the spring. In general single-acting cylinders offer a relatively short stroke.

Two different types of single-acting cylinders are available:

Single-acting cylinder **with base position minus**
(spring between head and piston)



Single-acting cylinder **with base position plus**
(spring between cap and piston)



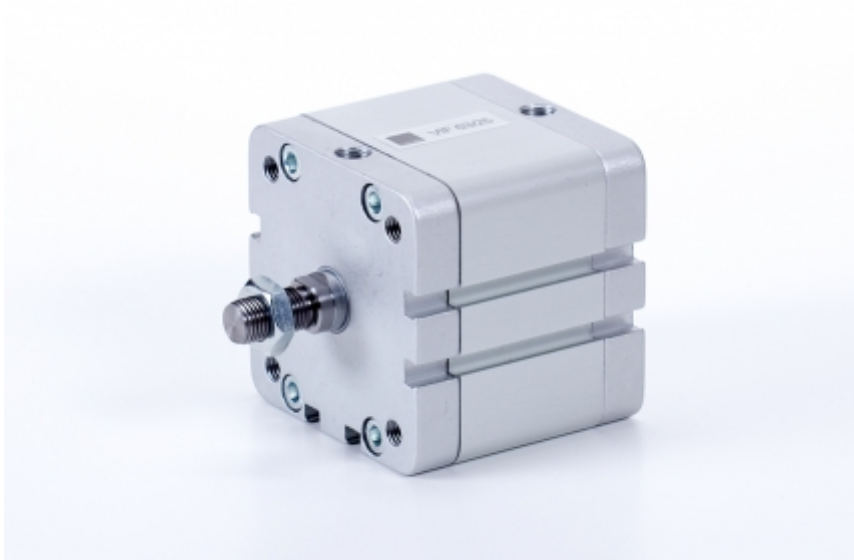
Chapter 7:

The pneumatic cylinder – part 1

Double-acting cylinders are driven in both directions by compressed air. They are always used when work has to be performed in both directions **or** when the required stroke is longer than the available springs.

There are different designs for different applications:

- **Double-acting cylinder**
(*standard design*)



- **Double-acting cylinder with through piston rod**
(*Cylinder has a piston rod on both ends*)



Chapter 7:

The pneumatic cylinder – part 1

- **Double-acting cylinder, guided / non-rotating rod**

(integrated guide unit for higher radial forces)



- **Cylinders with non-rotating piston rods**

(If the application does not allow a rotation of the piston rod, either a rod that does not have circular cross section or a double piston-rod is in use)

- **Multi-position cylinders**

(Two cylinders are assembled back to back. Thus 4 different strokes with different lengths are possible.)

- **Tandem cylinder**

(Target: Higher force of the cylinder without increasing its diameter. In order to achieve this, two or more cylinders are connected to each other so that their piston rods are connected as well and working in line. In other words several pistons use the same piston rod. Thus the force adds up.)

Chapter 7:

The pneumatic cylinder – part 1

5. ISO symbols

In order to distinguish between cylinders, there are also well defined ISO symbols and schemes indicating their different functions. These do not however indicate their size, diameter, stroke, ISO-standard etc.

Double-acting cylinder
(„standard design“)



Double-acting cylinder with
magnetic piston



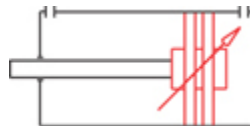
The piston is different from figure 1, indicating the magnetic piston.

Double-acting cylinder with
adjustable cushioning



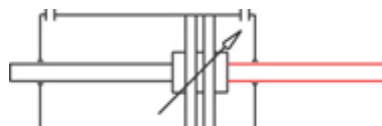
Cushioning symbolized by two rectangular objects; arrow for „adjustable“.

Double-acting cylinder with
adjustable cushioning and magnetic piston



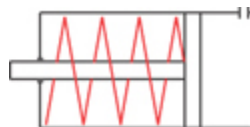
Combination of figure 2 and 3.

Double-acting cylinder with **through piston rod, adjustable cushioning and magnetic piston**



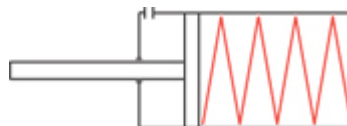
The through piston rod is added.

Single-acting cylinder (**MINUS**)



Single-acting cylinder with spring in minus chamber

Single-acting cylinder (**PLUS**)



Single-acting cylinder with spring in Plus chamber

Chapter 7:

The pneumatic cylinder – part 1



We introduced the following expressions:

- Cushioning
- Magnetic piston

Their explanation will follow in the next chapter. Just to give you a short insight:

- The **adjustable cushioning** slows the cylinder down when the piston is entering either head or cap. The idea is to avoid a hard shock when the piston hits these elements.
- The **magnetic piston** is required if we want to check the position of the piston with a REED-switch. The switch is added onto the outside of the cylinder. When the piston travels by, the switch sends a signal.

Chapter 8:

The pneumatic cylinder – part 2



In chapter 7 we looked at the most important features and characteristics of a pneumatic cylinder:

10. Design
11. Diameter and stroke
12. Movement
13. Number of positions
14. ISO symbols

In this chapter we will cover:

15. Cushioning
16. Detection of cylinder position (magnetic)
17. Speed control
18. International Standards

6. Cushioning

Compressed air can enter the cylinder at a very high speed. If the piston hits the cap or head at high speed, it can lead to damage. In order to avoid that, most cylinders are equipped with end-of-stroke absorbers / cushioning's, which reduce the piston's speed shortly before it reaches the cap and thus reduce shock.

There are two ways to reduce the shock:

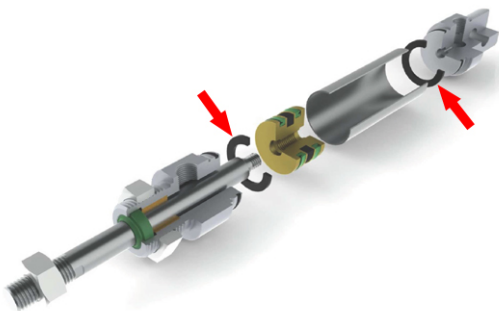
- flexible shock absorbers
- adjustable cushioning

Chapter 8:

The pneumatic cylinder – part 2

Flexible Shock Absorbers

The easiest way to avoid a hard shock is to assemble some kind of soft material between the piston and the cap/head. It comes in form of a ring which is usually made from polyurethane and thus offers very good shock-absorption. This design is often times used for cylinders with rather small diameters where the strain is not that high. The same kind is used for compact cylinders where the small dimensions do not allow any larger devices. The flexible shock absorbers are highlighted with red arrows in the graph below.



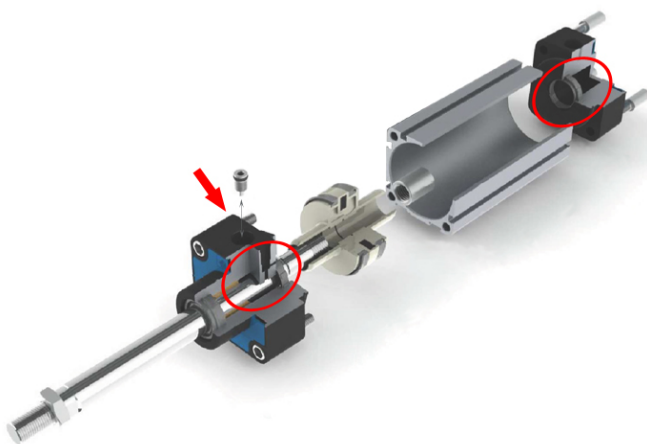
Adjustable (pneumatic) Cushioning

The adjustable pneumatic cushioning is used if it comes to stronger forces due to higher speeds or bigger sizes.

This way of reducing shock is efficient as well as wear-free. During the last 10 to 50 mm of its travel (depending on the size of the cylinder), the piston builds an air cushion inside the cylinder. The degree of cushioning (= speed reduction) can be adjusted at both ends of the cylinder for both sides respectively. The mechanism is a flow-regulating valve.

Both tie-rod and profile cylinders offer that feature, according to ISO 15552. Rodless cylinders often offer it, too. Round cylinders (ISO 6432) of larger diameters, as well as special cylinders, can be equipped accordingly.

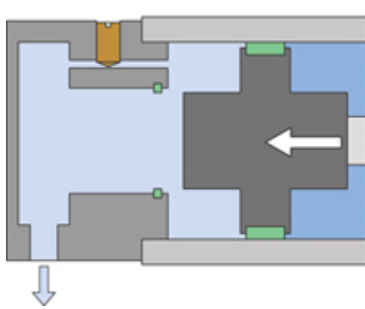
The components of the cushioning are marked with red in the graph below.



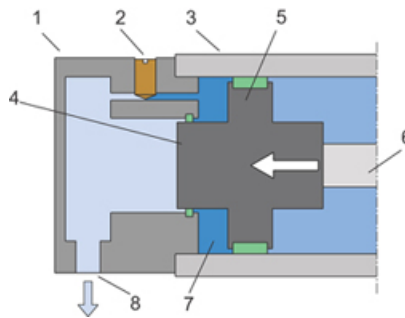
Chapter 8:

The pneumatic cylinder – part 2

Below you can learn more about **the function of the adjustable pneumatic cushioning**:



graph 1.



graph 2.

1. cylinder head
2. throttle screw
3. cylinder tube
4. brake piston
5. cylinder piston
6. piston rod
7. braking chamber
8. port / air connection

During the movement of the piston, the compressed air exhausts through the port (8) (graph 1).

Before the piston reaches the head, the brake piston (4) – which is part of the cylinder piston (5) – prevents the air within the braking chamber (7) from exhausting through the port (8) (graph 2). The air trapped there can only exhaust through a much smaller orifice. The orifice can be adjusted with the throttle screw.

Inside the **braking chamber** (7) pressure goes up and generates a temporary air spring. Its resistance remains there until the air has completely exhausted through the throttle screw (2).

CAUTION! The throttle screw can only adjust the degree of cushioning / speed of the cylinder piston for the last 10 to 50 mm of its movement.

How to adjust the speed of a cylinder in general will be covered later in this chapter.

Chapter 8:

The pneumatic cylinder – part 2

7. Detection of cylinder position (magnetic)

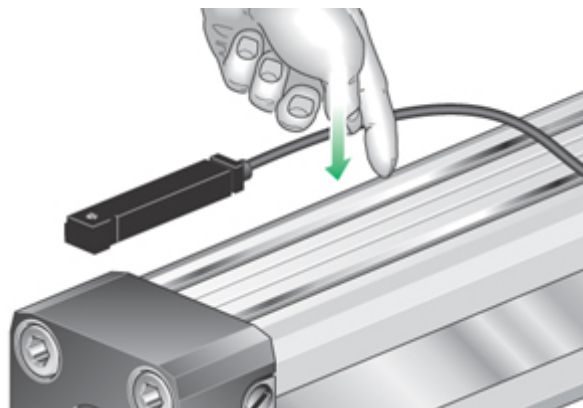
Sensors are absolutely necessary elements when it comes to industrial automation. Sensors generate information and control entire processes.

In order to detect the position of the piston, **sensors** which are triggered by a magnetic field are assembled onto the pneumatic cylinder. The **cylinder piston is equipped with a magnet** so that the sensor can receive a signal.

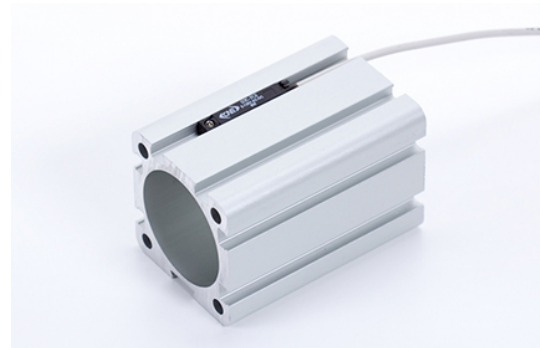
The sensor is assembled onto the cylinder in the position where the signal is required.



Many cylinders have an outer profile that offers space for assembling the sensor directly.



Sensor / switch ...



... assembled onto the tube

There are two different types of sensors / switches:

- **REED** switch
- **Inductive, PNP** switch

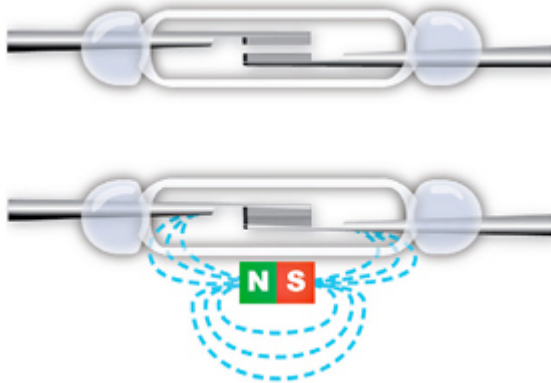
Chapter 8:

The pneumatic cylinder – part 2



REED switch

REED switches consist of two ferromagnetic nickel-iron wires. They are packed together in a glass tube filled with a noble gas and are made from a magnetic material.



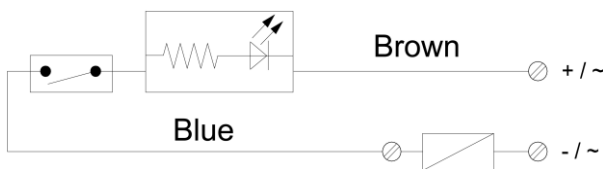
The magnet in the piston induces a magnetic field, making the shifting wires approach each other.

The shifting wires connect and close the electric circuit.

The switches have an LED that starts to glow when the circuit is closed.

The REED switches have 2 wires, which can be operated between 3 and 230 Volt AC/DC.

Symbol



Chapter 8:

The pneumatic cylinder – part 2

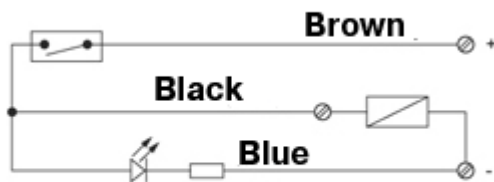
Inductive, PNP switch

The function of the inductive PNP switch is based on the principles of a bipolar junction transistor. When the magnet that is built into the piston gets close to the switch, it gives a well-defined signal. The switch can be used 'normally open' as well as 'normally closed'.

An LED displays the condition of the switch.

PNP switches have generally 3 wires. They work within a voltage range of 5 to 30 V DC.

Symbol



Advantages of the PNP switch in comparison to the REED switch:

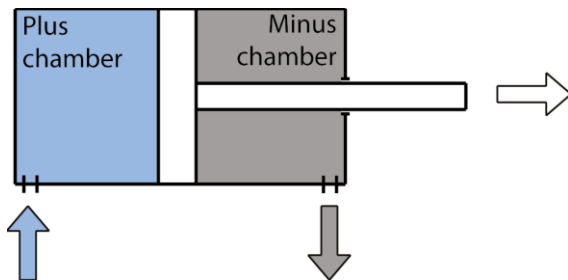
- No movable parts inside
- Higher frequency
- Higher durability

Chapter 8:

The pneumatic cylinder – part 2

8. Speed control of cylinders

To control the speed of a pneumatic cylinder (actuator) over the entire stroke, flow regulators or flow-regulating silencers can be used.



For the positive movement of a double-acting cylinder, compressed air enters the plus chamber. Simultaneously, the air in the minus chamber exits. (controlled by a 5/2-way valve)

Ideally, we control the speed of the cylinder by reducing the flow of the exiting air.

To control the speed, we regulate the exhaust air flowing out of the cylinder chamber. We thereby avoid an immediate exhaust. The air in both chambers is available as long as the piston has reached the end position. The movement is therefore very smooth.

CAUTION! In order to set the speed of the cylinder and to get a smooth movement, it is always the **exhaust air** that has to be controlled.

To do this there are different products available for speed regulation:

- Uni-directional flow regulator – block form flow regulator
- Uni-directional flow regulator – function fitting to be assembled in the cylinder
- Uni-directional flow regulator – function fitting to be assembled in the valve
- Exhaust flow regulator – to be assembled into the valve

Chapter 8:

The pneumatic cylinder – part 2

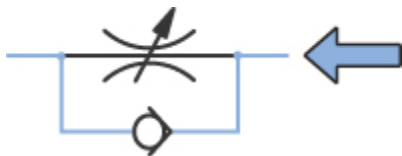
Uni-directional flow regulator = one-way flow control valve

In order to allow compressed air to flow into the cylinder at full speed, while allowing it to exhaust slowly, we use a **one-way flow control valve**.



Throttled air-flow:

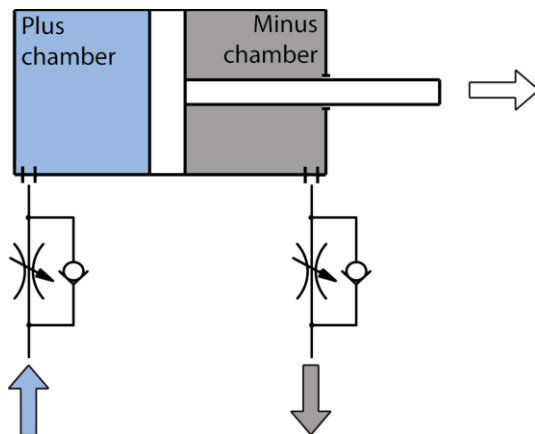
Air flowing this way has to pass the throttle (flow regulator) as the other path is blocked by a check valve.



Free air-flow:

Air flowing the opposite direction can bypass the throttle and passes through the check-valve (non-return valve).

By using two one-way flow control valves, we can independently regulate the positive as well as the negative movement of the cylinder.



During **positive movement**, air bypasses the flow regulator into the plus chamber. Air that is supposed to leave the minus chamber has to pass through the throttle in the flow regulator. This limits the speed of the cylinder.

During **negative movement**, the air flows through the same block form flow regulators. This time the air flowing into the minus chamber bypasses the throttle while the exhaust of the plus chamber is regulated.

The speed of the positive movement has to be adjusted at the regulator of the minus chamber and vice versa.

There are many different designs of flow-regulators available and their sizes differ depending on the manufacturer.

Chapter 8:

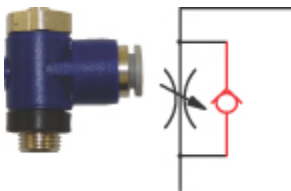
The pneumatic cylinder – part 2



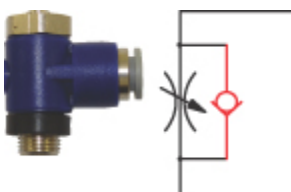
Function fittings are screwed either directly into the cylinder or into the valve. Therefore there are two different types, one for each area of application.

- A flow regulator **for a cylinder** reduces the flow that streams from the thread to the push-in fitting (out of the cylinder).
- A flow regulator **for a valve** regulates the flow from the push-in fitting to the threaded port (into the valve).

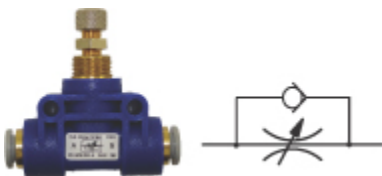
There are products where the manual adjustment can be done with a screw-driver or with a knurled-head screw.



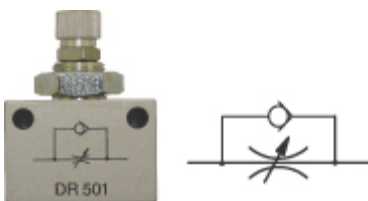
Function fitting with one-way flow regulator for cylinder



Function fitting with one-way flow regulator for valve



One-way flow regulator with two push-in fittings



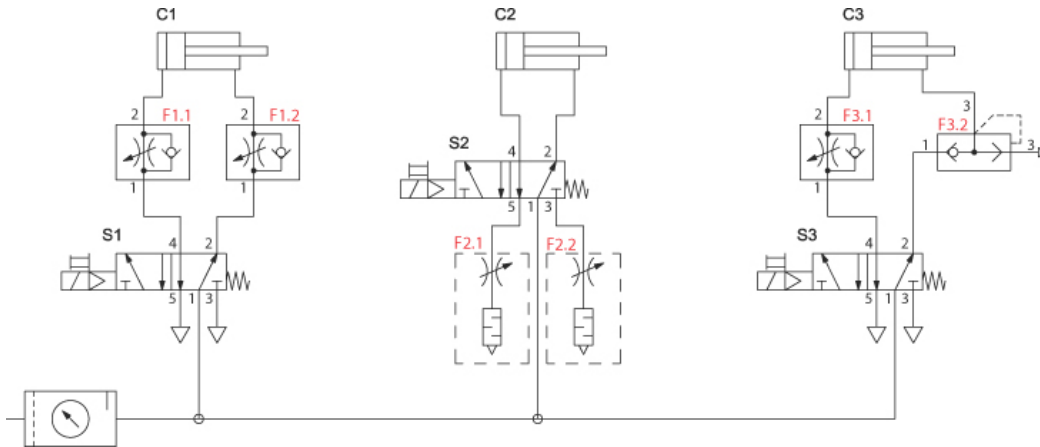
Block form flow regulator with two female ports

Chapter 8:

The pneumatic cylinder – part 2

Sample circuits for cylinders with speed control

Below you see three different ways of speed control for a double-acting cylinder, with air supply via a joint FRL.



Circuit 1 (Cylinder C1):

The double-acting cylinder C1 is controlled by the single solenoid 5/2-way valve S1. As soon as the valve is actuated, air flows into the Plus chamber of the cylinder via F1.1. The air flow is not restricted by F1.1. Simultaneously, air needs to exhaust from the Minus chamber of the cylinder via F1.2. This flow is restricted by F1.2. Via the directional valve S1 (port 3), the air is finally exhausted. As soon as the electric actuation of the directional valve S1 is taken away, the valve switches back to normal position. Air flows at full speed via F1.2 into the Minus chamber of cylinder C1, while the air in the Plus chamber exits via F1.1 and S1, exhausting at port 5 of S1. This flow is restricted by / adjusted at F1.1. The positive movement of the cylinder is regulated at F1.2, the negative movement is restricted at F1.1. F1.1. and F1.2. can be screwed either into the cylinder or the valve, but the correct version has to be selected either way!

Circuit 2 (Cylinder C2):

The double-acting cylinder C2 is controlled by the single solenoid 5/2-way valve S2. The speed of the cylinder is adjusted at flow control silencers F2.1 and F2.2., which are screwed into the valve. For positive movement, the directional valve S2 needs to be actuated. Air streams at full speed from port 1 to port 4 of the valve and into the Plus chamber of cylinder C2. At the same time air needs to exhaust from the Minus chamber of the cylinder. The air streams into port 2 of the valve S2. Its flow is restricted by F2.2 before leaving the valve S2 at port 3. For negative movement, the valve switches back into standard position. The Minus chamber is supplied via port 2 of valve S2. The exhaust from the Plus chamber is restricted by F2.1 in port 5 of the valve S2.

Circuit 3 (Cylinder C3):

The double-acting cylinder C3 is controlled by the single solenoid 5/2-way valve S3. For an extremely quick positive movement after actuating the valve, the Minus chamber is exhausted by the quick exhaust valve F3.2.; the exhaust air does not pass the directional control valve S3. For negative movement, the valve S3 needs to switch back into normal position. The exhaust air of the Plus chamber has to go through the one-way flow regulator F3.1

Chapter 8:

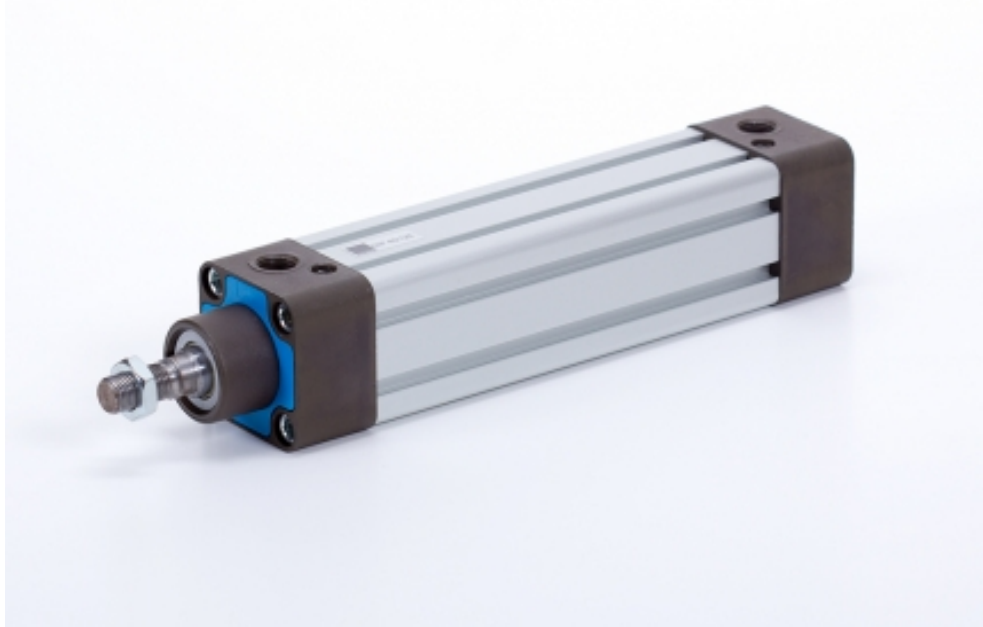
The pneumatic cylinder – part 2

9. International Standards

The most common cylinders in pneumatics have been standardized, the target being maximum compatibility between products of different manufacturers.

The most common cylinder standards are:

ISO 15552 | **VDMA 24562** | **DIN ISO 6431** (old standard) | for profile and tie-rod cylinders.



Chapter 8:

The pneumatic cylinder – part 2

DIN ISO 6432 | round cylinders



Chapter 8:

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ISO 21287 | compact cylinders



Chapter 8:

The pneumatic cylinder – part 2

UNITOP | compact cylinders



Chapter 8:

The pneumatic cylinder – part 2



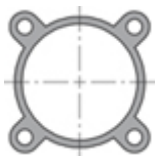
The HAFNER ISO 15552 cylinders

The standard **ISO 15552** is valid since 2004. The previous and very closely related standard was **ISO 6431** (1992 - 2004).

The standard defines piston diameters ($\varnothing 32 \dots \varnothing 320$ mm), maximum pressure (10 bar), and distinct features and dimensions, as well as standard accessories.

Thus any **accessories** are also **mostly interchangeable**.

The ISO 15552 cylinders in the HAFNER range have the type number **DIL** and **DIP** (for products with a run-through piston rod: **DBL** and **DBP**)



DIL cylinder

The more economic solution since little material is used for the profile. Easy to clean. Any sensors have to be assembled with special fixing elements.

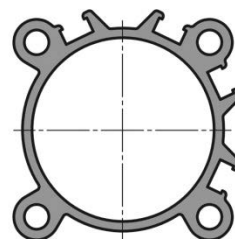


DIP cylinder

Switches can go into the groove, easy assembly, no additional parts.

Since 2016 HAFNER have been offering another range of economically-priced profile cylinders

called "**H-series**".



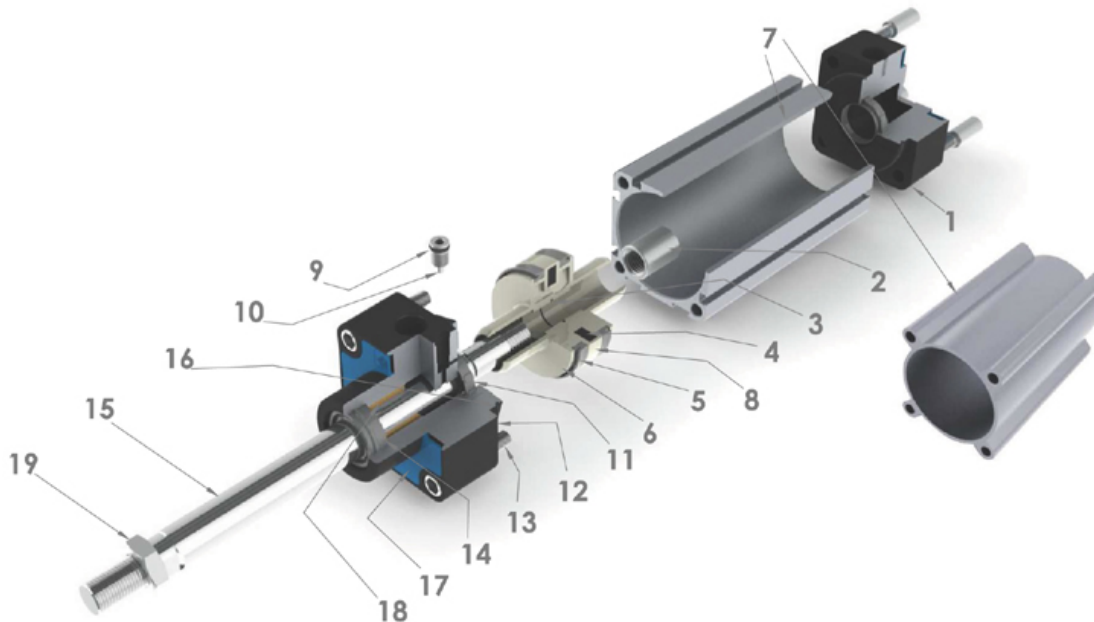
HIF cylinder

Switches can go into one of the four grooves of the profile tube.

Chapter 8:

The pneumatic cylinder – part 2

Materials used in an ISO 15552 cylinder of the D-series:



#	Description	Material
1.	Cylinder cap	Aluminum, anodized
2.	Fixing nut for piston	Steel, nickel plated
3.	O-Ring (seal between piston and piston rod)	NBR
4.	Magnet	Ferromagnetic material
5.	Piston seal	Polyurethane
6.	Piston	Techn. polymer (or aluminum)
7.	Tube	Aluminum, anodized
8.	Guide	Techn. polymer
9.	O-Ring (seal for cushioning)	NBR
10.	Screw (for cushioning)	Steel, nickel plated
11.	Mobile seal (for cushioning)	Polyurethane
12.	Cylinder head	Aluminum, anodized
13.	Screws	Steel, nickel plated
14.	Seal for piston rod	Polyurethane
15.	Piston rod	Chromed steel or stainless steel
16.	O-Ring (seal between head and tube / cap and	NBR
17.	Covers	PA
18.	Bushing / bearing for piston rod	Sintered bronze
19.	Nut at piston rod	Steel, nickel plated

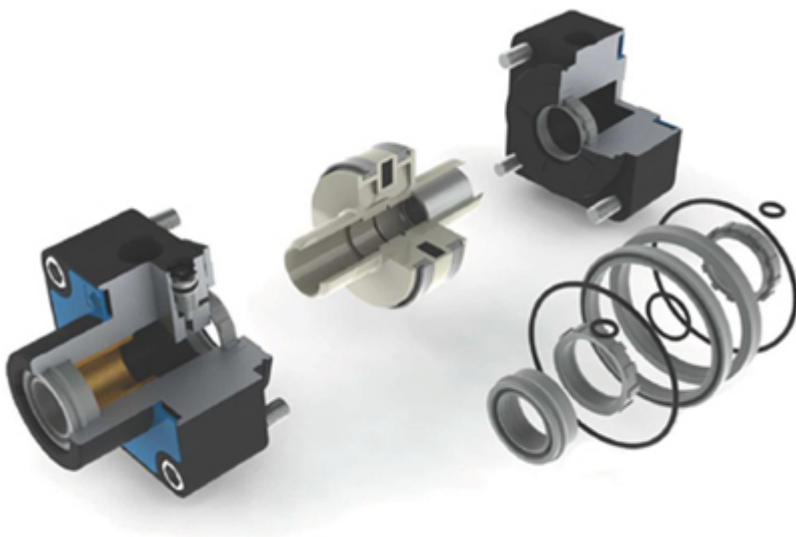
Chapter 8:

The pneumatic cylinder – part 2

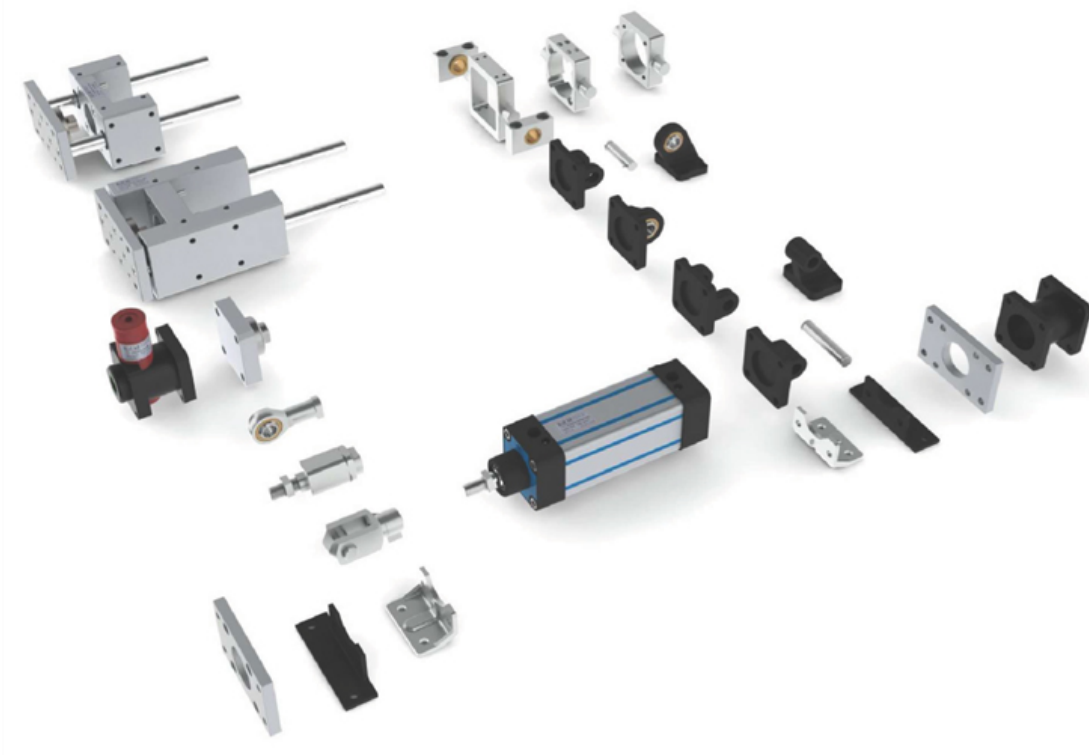


Due to high speeds, long strokes and high frequencies the seals can wear out faster than other parts. Therefore we offer spare-part kits for the cylinders. The spare-part kits contain all potentially worn-out parts.

Repair kits for cylinders types DIL, DIP, DBL and DBP have the order code **DIR**.



Standard ISO 15552 also defines the dimensions of the **fixed accessories**. Therefore any accessories by different manufacturers will be mostly compatible.



Chapter 9:

The basics of air preparation



Compressed air

CAUTION! The quality of the compressed air in use is substantially important for the safe operation and durability of the pneumatic system.

Air consists of: **Nitrogen** (N₂) 78,09 %, **Oxygen** (O₂) 20,95% and **Argon** (Ar) 0,93 %. 0,03 % of the volume is made up by **other gases**, such as CO₂, Methane and various noble gases. Air can be polluted by sulfurous gases, carbon-monoxides and dirt, damp, or particles.

When producing compressed air (compressing the environmental air), and when transporting it through the tubes, other harmful elements may enter.

In order to define the quality of compressed air, there are **standardized purity classes**.

Purity classes for compressed air in accordance to ISO 8573-1

Compressed air is classified. The three most important elements of pollution are **particles, water and oil**.

They are classified in accordance to their degree of concentration within the air and displayed as follows:

ISO 8573-1:2010 [A:B:C]

A – particles | 0 ... 8, X

B – water | 0 ... 9, X

C – oil | 0 ... 4, X

In case an element is displayed as **class X** (= an element with a high concentration), its amount or the degree of concentration needs to be put in round brackets. The following example shows the quality of air where the water concentration is at Cw 15 g/m³. Therefore we indicate its purity as follows:

ISO 8573-1:2010 [4:X(15):3]

Chapter 9:

The basics of air preparation



Purity classes for compressed air in accordance to ISO 8573-1

ISO 8573-1:2010							
Class	Particles				Water		Oil
	Maximum number of particles of the following size [µm] / m ³ of compressed air			Concentration	Pressure dew point °C	Content of liquid [g/m ³]	Total content (liquid, aerosol, gas) [mg/m ³]
	0,1 ... 0,5 µm	0,5 ... 1 µm	1 ... 5 µm	[mg/m ³]			
0.	By definition of the user, less contamination than class 1						
1.	≤ 20 000	≤ 400	≤ 10	-	≤ -70	-	≤ 0,01
2.	≤ 400 000	≤ 6000	≤ 100	-	≤ -40	-	≤ 0,1
3.	-	≤ 90 000	≤ 1000	-	≤ -20	-	≤ 1
4.	-	-	≤ 10 000	-	≤ +3	-	≤ 5
5.	-	-	≤ 100 000	-	≤ +7	-	-
6.	-	-	-	≤ 5	≤ +10	-	-
7.	-	-	-	5 ... 10	-	≤ 0,5	-
8.	-	-	-	-	-	0,5 ... 5	-
9.	-	-	-	-	-	5 ... 10	-
X	-	-	-	> 10	-	> 10	> 5

In normal pneumatic applications the following air quality is sufficient: **ISO 8573-1:2010 [7:4:4]**.

According to the ISO norm, the permitted degrees of pollution are:

- Particle concentration **5-10 mg/m³**
- Dew point less than **3 °C**
- Oil concentration max. **5 mg/m³**

For specific applications or in extreme environments (e.g. railway application in cold climates), a higher air purity might be required.

Chapter 9:

The basics of air preparation



Basics regarding the generation and preparation of compressed air

When generating compressed air, it is important to ensure it to be as oil-free as possible at the lowest possible cost. The preparation of compressed air has the same economical aspect.

It is possible to generate compressed air of a high quality – i.e. oil-free or with reduced oil-content – with compressors that work both with and without lubrication if a sound air preparation has been established.

The environmental air and its quality

The air's quality highly depends on external, environmental factors. **The concentration of hydro-carbonates** due to industry or traffic can reach levels of **4-14 mg/m³**.

In factories the **oil content** can exceed **10 mg/m³** because of coolant and lubrication fluids in the machinery.

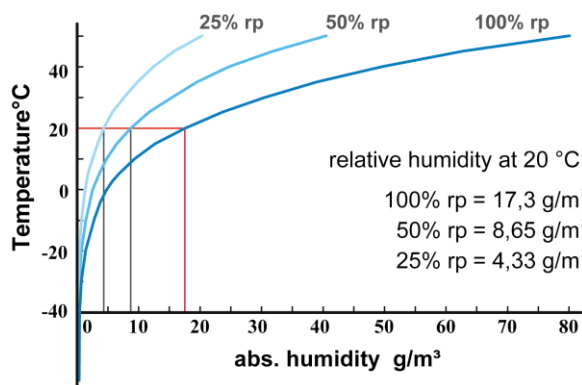
Moreover there are other polluting elements such as sulfur dioxide, soot, metals, **dust** and **humidity**.

How to define „oil-free“ compressed air?

According to ISO 8573-1 compressed air can be called “oil-free“ when the content of oil (including oil dust) is **less than 0,01 mg/m³**. That is about 4 % of the oil content in normal air, so it is hardly detectable. You can find such requirements for very high air purity e.g. in the food and pharmaceutical industry as well as the electronics industry (manufacture of wafers etc.).

Where does humidity come from?

There is always humidity in the environmental air. The **degree of the humidity depends on temperature and air-pressure**. The warmer it is, the higher the ability of air to hold water. At higher pressure that ability weakens.



Absolute humidity: amount of water in 1 m³ air.

Max. humidity (saturation): highest possible amount of water in 1 m³ air at the given temperature and pressure.

Relative humidity: the degree of humidity in relation to max. humidity (%) at this temperature.

Chapter 9:

The basics of air preparation



Formula:

$$\text{Relative humidity} = \frac{\text{Absolute humidity}}{\text{Maximum humidity}} \cdot 100 (\%)$$

The table below displays the max. humidity values of air (saturation values) at different temperatures:

Temperature (°C)	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
Water content (g/m ³)	0,4	0,7	1,1	1,6	2,4	3,4	4,8	6,8	9,4	12,8	17,3	23,1	30,4	39,6	51,2

If the humidity becomes higher than 100% relative humidity the excess water is released. The temperature at which water is released at the given air-water concentration is called the **dew point**.

Water is released when the temperature goes down and/or when air pressure rises. **This is exactly what happens in the compressor as well as in the air-cooler.** The water that is released forms the so-called **condensate**.

The drying of compressed air

When air gets cooler, it releases water.

Example:

A screw compressor working at a **temperature of 20°C, at sea-level**, has a **suction capacity of 10 m³** per minute; **the relative humidity** of the environmental air is **60 %**.

Looking at the table above, we can see that at 20°C **100%** humidity = 17.3 g water / m³ air. So we can deduct that **60%** humidity = 10.4 g water / m³

Thus the 10 m³ contains 104 g of water.

At a compression ratio of 1:10 (10 bar), the compressor generates **1 m³** of compressed air **per minute** (10 m³ environmental air = 1 m³ compressed air).

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The basics of air preparation



During compression the air's temperature rises to around 80 °C. At this temperature it can hold 290 g water / m³ air (referring again to the table above). Therefore its **relative humidity is at only 36%** (104 / 290 = 36%). The air is relatively dry and produces no condensate.

A **cooler** after the compressor cools the compressed air down from **80 °C to approx. 35 °C**. At 35°C the air can only hold 39.6 g / m³, though there are 104 g of water inside each m³. So **64 g / m³ will be released**. This means we have 64 g of excess water every minute the compressor operates. This translates (x 60 x 8) into **31 liter of condensate after an 8 hour shift**.

In order to have fairly **safe working conditions, this condensate needs to be removed**. The **drying** (= cooling) **of the generated compressed air is an essential part of the generation and preparation of compressed air**.

CAUTION! Without properly drying the air you will find a lot of condensate in the air-tank as well as in your pipelines, machinery and many other places.

CAUTION! The standard filters of an FRL-unit (50 ... 0,01 Mikron), **do not influence the content of water**. They are made for filtering particles. The water you will find in the condensate drain of a filter consists only of a few drops. It is irrelevant in comparison to the amounts of water mentioned before.

How to dry the air?

The drying of compressed air in an industrial environment is usually achieved with one of the following methods:

- **Deliquescent dryer**

A deliquescent dryer typically consists of a container filled with hygroscopic material that absorbs the water. Advantage: No additional energy is required. Disadvantage: The hygroscopic materials have to be replaced regularly.

- **Desiccant dryer**

Also called twin tower dryer or adsorption dryer. The air flows through a desiccant material such as silica gel. The gel's ability to keep water is limited, but can be easily reset by blowing the water out ("purging" the gel). No additional energy is required here either, but there is a loss of compressed air due to the purge. Large equipment is needed for air flows at high speeds.

Chapter 9:

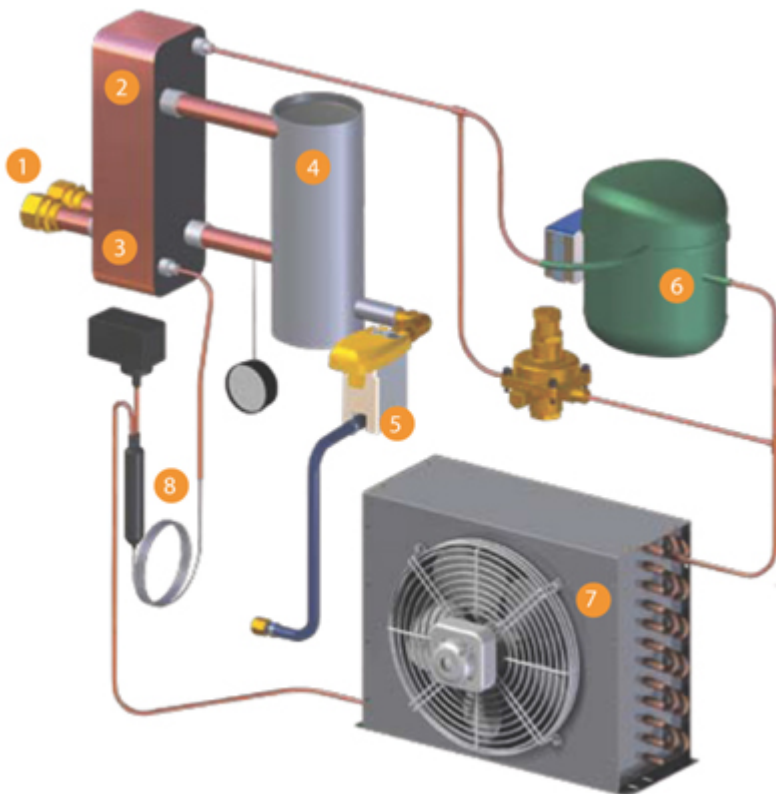
The basics of air preparation

- **Membrane dryer**

First the air has to be filtered with a high quality coalescing filter, then the air passes through a center bore of a hollow fibre in a membrane bundle. Dryer air is floating outside the membrane. This leads to an exchange of vapor. Disadvantage: the flow is limited to around 1000 l/min.

- **Refrigerated dryer**

Refrigerated drying is based on the principle that colder air can hold less water. The air passes a heat-exchanger that is cooled to around 3°C. The cooled-down air loses water as well as oil, both of which are collected. After drying the air is filtered.



Components of a refrigeration dryer

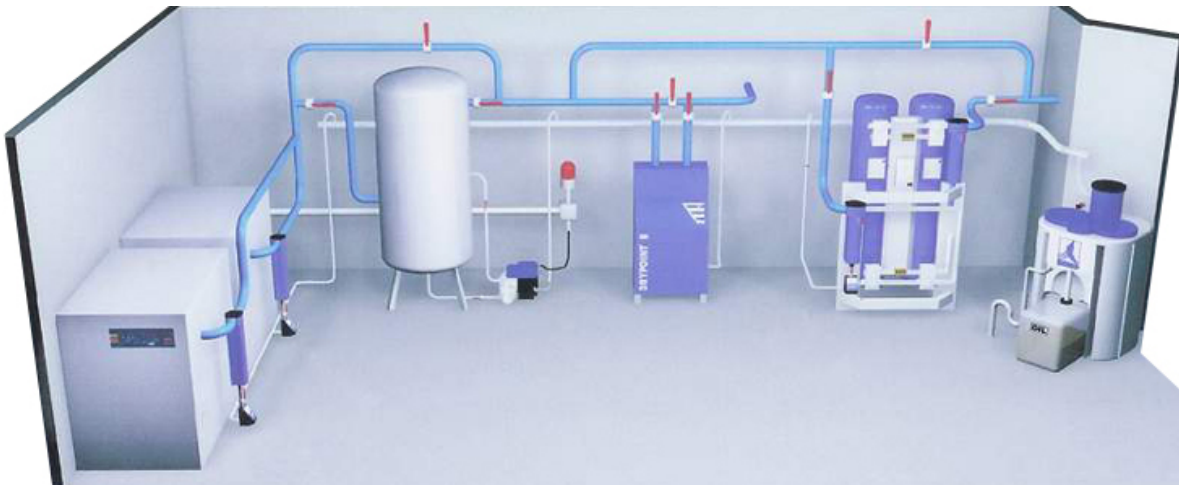
1. Air-in and air-out
2. Air-to-air head exchanger
3. Air-to-refrigeration heat exchanger
4. Condensate separator
5. Condensate drain
6. Cooling compressor
7. Cooling ventilator
8. Cooling medium injector

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The basics of air preparation

Why is air-preparation necessary?

You could look at a compressor as a big vacuum cleaner. It sucks in everything from the environment. When generating compressed air, all the environmental elements of pollution are concentrated. Everything is fed into the pneumatic system.



FRL-units are an important element of the pneumatic system. With these units the air can reach the required quality since they have filters for cleanness, lubrication for oil content and can manage pressure. Well-processed air does not only ensure a safer workspace but also increases the durability of the equipment.

Air preparation equipment consists of:

- Filters
- Pressure regulators
- Lubricators
- Switch-on and starter valves
- Distributors, pressure switches

We can categorize them by design, size, flow rates and port size. There is a wide range available, from port size G1/8" to G3".

Chapter 9:

The basics of air preparation

The following pictures show a selection of the most common elements:



Filter



Regulator



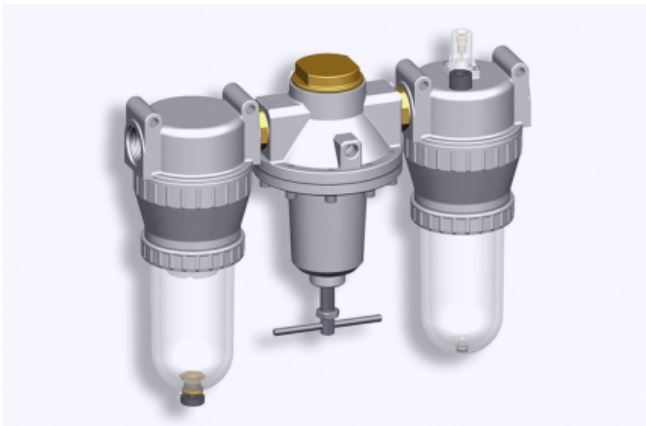
Lubricator



Filter-Regulator Unit

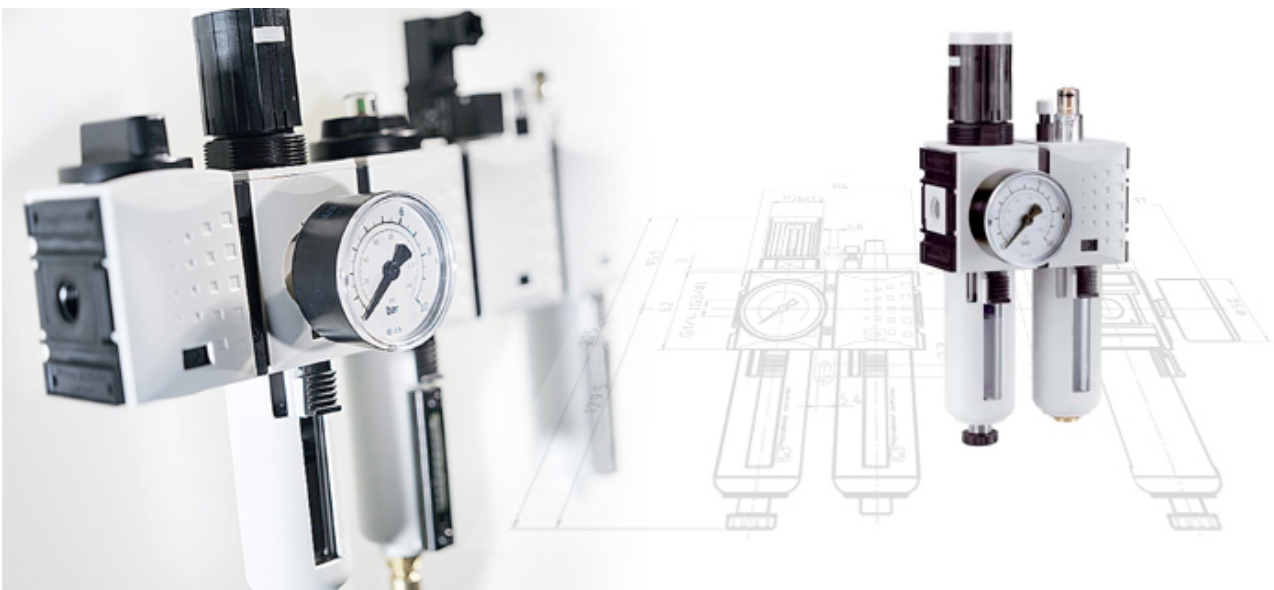
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FRL-unit, consisting of a filter, a regulator and a lubricator

Modular FRL-units offer a high degree of flexibility to the user since these individual products can be assembled easily into a whole unit.



Chapter 10:

Air Preparation Units

Filtering of compressed air

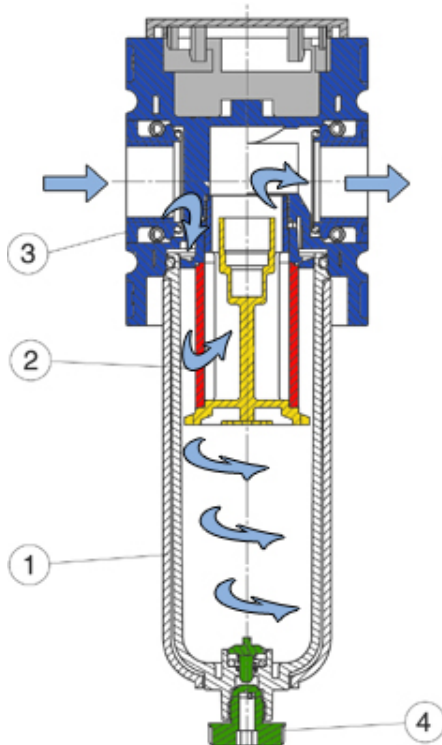
The task of the filter is to filter out particles and to remove the condensate released by the compressed air.

CAUTION! Filters (50 to 0,01 Micron) have no influence on humidity, they filter particles depending on the fineness of the filter elements. The water that is found in the condensate drain only consists of drops and is relatively irrelevant.

Sometimes several filters are necessary in a system because of different requirements:

- Pollution from the pipeline or condensate released during transportation has to be removed before reaching individual equipment.
- Different pieces of control or regulating equipment require different air quality.
- For specific applications (e.g. the packaging of food) standard filtration is insufficient. Activated-carbon filters are required. The air used in these filters has to be pre-filtered by fine-filters.

In pneumatics **cyclonic filtration** is often used to separate particles and condensate from the medium.



Cyclonic separator

1. Filter bowl
2. Filter element
3. Body
4. Condensate drain

A high-speed rotating (air) flow is established within a cylindrical or conical container, called a **cyclone**.

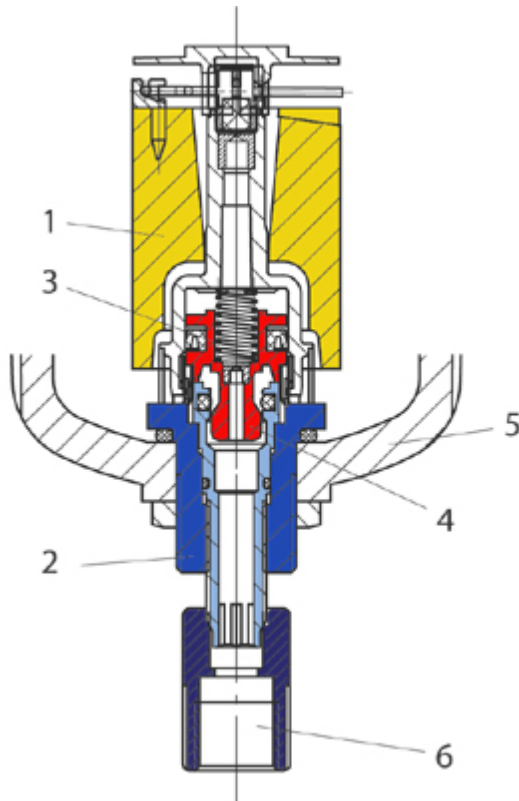
Due to the centrifugal force, particles and condensate fall towards the outside and drop to the bottom.

In addition, the medium flows through a filter element that catches smaller particles. The fineness of the filter element determines the max. size of particles. Polluted condensate can be drained from the bottom of the bowl.

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Air Preparation Units

An automated drain valve works as a floating exhaust valve. As soon as the condensate reaches a certain level, the valve opens and drains the bowl.



Automated condensate drain

1. Float sensor
2. Body
3. Spring
4. Closing element
5. Bowl
6. Port for condensate – manual override

How it works:

Without pressure the closing element (4) is in an open position. The condensate that is concentrated at the bottom of the bowl (5) is drained.

At an operating pressure of around 1,5 bar the valve closes the drain.

In case that during operation (pressure in the filter element) the condensate rises high enough to lift the floater, the valve opens the drain and the condensate is blown out of the bowl. Thus the level of condensate is lowered and the drain closes again.

Automated drains can also be operated manually. By turning the knob at the bottom, the drain is on manual mode and the condensate is blown out of the bowl (if there is air pressure) / drips out of the bowl (without air pressure).



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Depending on the requirements inside the pneumatic system there are different filter elements offering different degrees of fineness and materials.

In pneumatics we typically use **filter elements with a finesses of 5 to 50 µm**.

In order to reach an air quality according to ISO 8573-1:2010 [7:4:4], the following is required:

- Concentration of particles: **5-10 mg/m³**
- Filter fineness: **20-50 µm**

In case of **higher requirements**, we recommend standard **ISO 8573-1:2010 [6:4:4]** which is still common in pneumatics:

Concentration of particles: **Maximum 5 mg/m³**

Filter fineness: **5 µm**

Based on make and fineness of the filter element, we differentiate between **filters**:

- **Classic filter unit**
 - Filter fineness: 5 µm, 20 µm, 50 µm
 - Material: sintered PE, sintered bronze on request
- **Pre-filter unit**
 - Filter fineness: 0,3 µm
 - Material: cellulose-acetate
- **Fine-filter unit**
 - Filter fineness: 0,01 µm
 - Material: glass fibre with acetate
- **Activated-carbon filter**
 - Material: activated-carbon

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Classic filter unit

Pre-filter unit

Fine-filter unit

Activated-carbon filter unit

(KFIL)

(KPFI)

(KCFI)

(KAFI)

Filter fineness: **5 µm**

Filter fineness: **0,3 µm**

Filter fineness: **0,01 µm**

Filter fineness: n.a.

Oil content: **0,1 mg/m³**

Oil content: **0,01 mg/m³**

Oil content **0,005 mg/m³**

Class 2 (ISO 8573-1)

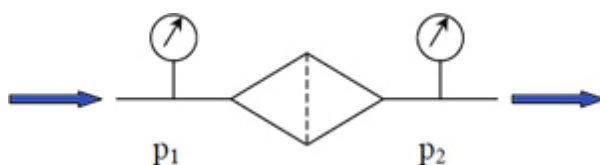
Class 1 (ISO 8573-1)

Class 0 (ISO 8573-1)



Durability of the filter elements

Filter elements need to be exchanged on a regular basis since their flow will be reduced over time due to pollution. The loss of air-pressure can be detected by measuring the differential pressure in front of and behind the filter.



$$\Delta p = p_1 - p_2$$

Measuring differential pressure with a gauge:

The dirtier the filter element, the larger the pressure drop inside the filter. The pressure difference is measured between 0 and 0,5 bar, which shows how much blockage there is in the filter element.

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Pressure regulation with a regulator

Normally the network supplies pressure between 6 and 10 bar, which can vary depending on the rate of air consumption.

In order to use compressed air efficiently, the required pressure should be set for each piece of equipment with an individual pressure regulator. The individual pressure can only be lower than the pressure supplied by the network.

It is the task of the pressure regulating valve to hold the level of the output pressure on a constant level, regardless of input pressure or fluctuations in air consumption.

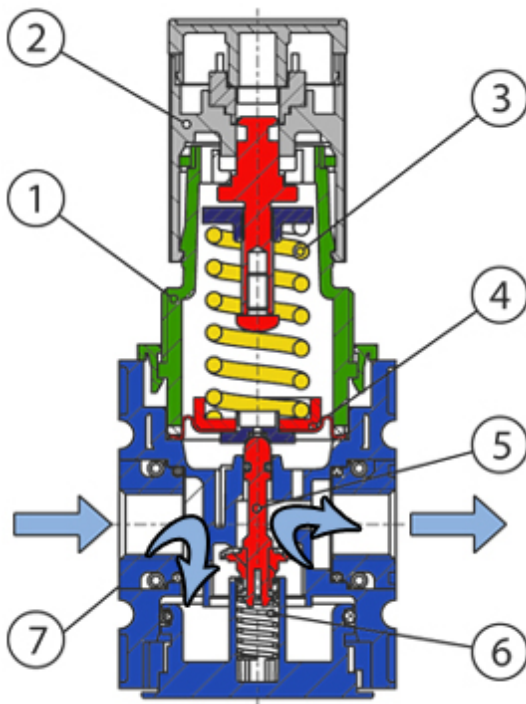
We differentiate between **regulators with secondary venting** and regulators **without secondary venting**.

Regulators with secondary venting can let out excess pressure on the secondary side, e.g. when the pressure P2 is reduced by the operator or when the pressure is increased by the equipment (high load on a large cylinder).

Regulators without secondary venting are usually used when the medium is not supposed to be released into the atmosphere.

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Air Preparation Units



Regulator, with secondary venting

1. Body – spring casting
2. Knob to set pressure
3. Spring
4. Diaphragm
5. Seat with valve disc
6. Counter-pressure spring
7. Body

Essential for the pressure regulation is the diaphragm (4). On the surface below the diaphragm, the secondary pressure is in effect, against which the force of the set spring (2) works from the top.

If the force of the air pressure is weaker than that of the spring, the diaphragm is pushed down and the valve rod (5) is opening the poppet valve. Pressure is rising.

In case there is less consumption, pressure below the diaphragm builds up. The force of the air is larger than that of the spring, and the valve disc is gradually closing, eventually fully closing the valve seat.

If secondary pressure exceeds the pressure that was set, the diaphragm is pushed upwards and the secondary exhaust is opening up (if the regulator is equipped with a secondary vent).

Secondary pressure can be displayed by a pressure gauge.

CAUTION! Pressure regulation in pneumatics is a **regulation of volume**. The amount of compressed air behind the regulator needs to be large enough to build up an air pressure that is the same as set at the regulator (off-setting the force of the spring in the regulator). If the pressure drops, more air is fed into the system behind the regulator. There must be a balance between the force of the air-pressure and the force of the spring.

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Air Preparation Units

Lubricating the compressed air

Neither control-elements nor actuators are separately lubricated in a pneumatic system. In order to avoid wear-out, lubrication can help. Unnecessary friction also increases energy consumption.

The goal of the manufacturers of the components is to design products that do not require any individual lubrication. This can be realized by selecting the right materials, choosing the right seal system, reducing friction, or supplying the product with **sufficient (life-long) lubrication** when initially sold. For this kind of lubrication, special types of grease are available. They are designed to constantly stay in the valves or cylinders. In order for the lubricant to avoid washing-out, the air needs to be dry since water has a negative effect on it as well.

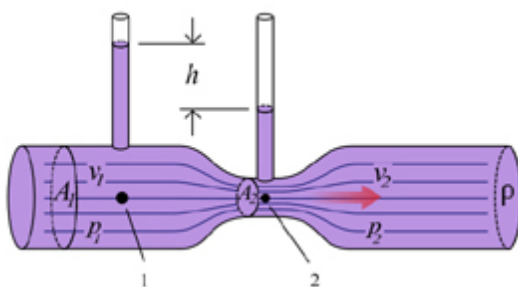
The same washing-out effect is true when lubricators are used. **Therefore, if lubricators are in use, they must not run dry!**

→ **The eternal question: "Should lubricators be used or not?"**

Answer: It always depends on the application!

In certain industries (e.g. food industry) lubrication is not allowed at all. In other industries with very big cylinders and strong forces, lubrication can be really beneficial, especially for the durability of the actuators.

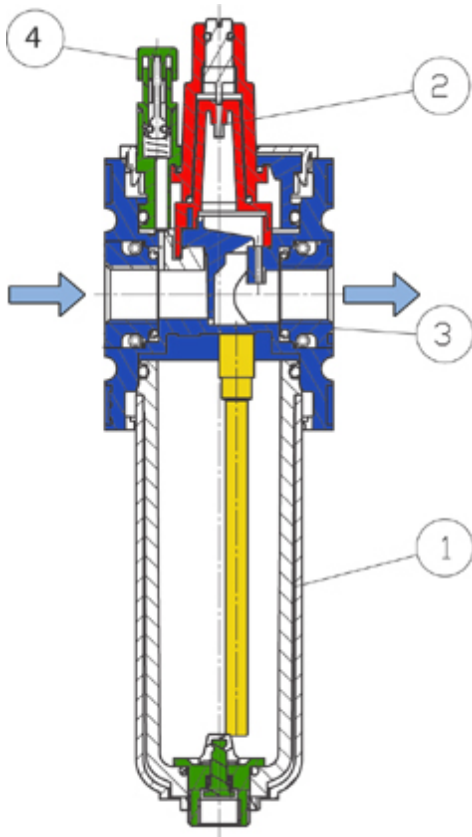
The lubricators in pneumatic systems use the **Venturi principle**.



A pressure difference is generated by forcing the compressed air through a jet. Behind the jet the pressure is lower.

This pressure difference sucks oil from the container into the air stream where it is dispersed very finely. The same principle is used in a carburetor of a car running on petrol.

Chapter 10: Air Preparation Units





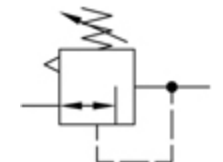

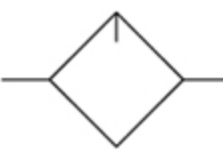

Lubricator

1. Oil container
2. Dosing unit
3. Body
4. Knob to activate sucking function for refill.

Some lubricators have a device that enables oil to be sucked in while the equipment is pressurized with the aid of a vacuum.

At the bottom of the body, a tube has to be connected. The end is to be held into the oil. Press the button (4) and the lubricator is refilled with oil.

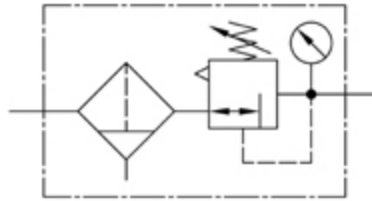
Air preparation units – pictures and ISO symbols

Filter unit		
Pressure regulator		
Lubricator		

Chapter 10:

Air Preparation Units

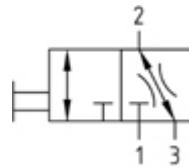
Filter regulator with pressure gauge



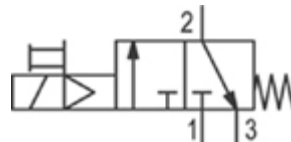
FRL-unit (filter, regulator, lubricator and pressure gauge)



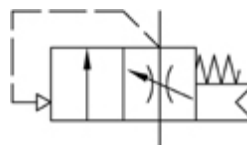
Manually-actuated main switch-on valve, 3/2-way



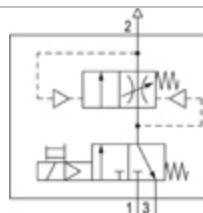
3/2-way solenoid valve with manual override



Soft starter valve



Soft starter valve with electric actuation



Chapter 10:

Air Preparation Units



CAUTION! It is insufficient to have only one filter and one pressure regulator for the entire system. Due to the volatile consumption of compressed air, the different pieces of equipment need individual air preparation (pressure, sometimes also different air quality, filtration / lubrication).

We recommend to locally prepare the compressed air for the different pieces of your equipment. This reduces wear-out and increases the durability of machines and equipment.

There are many products to choose from:



Futura



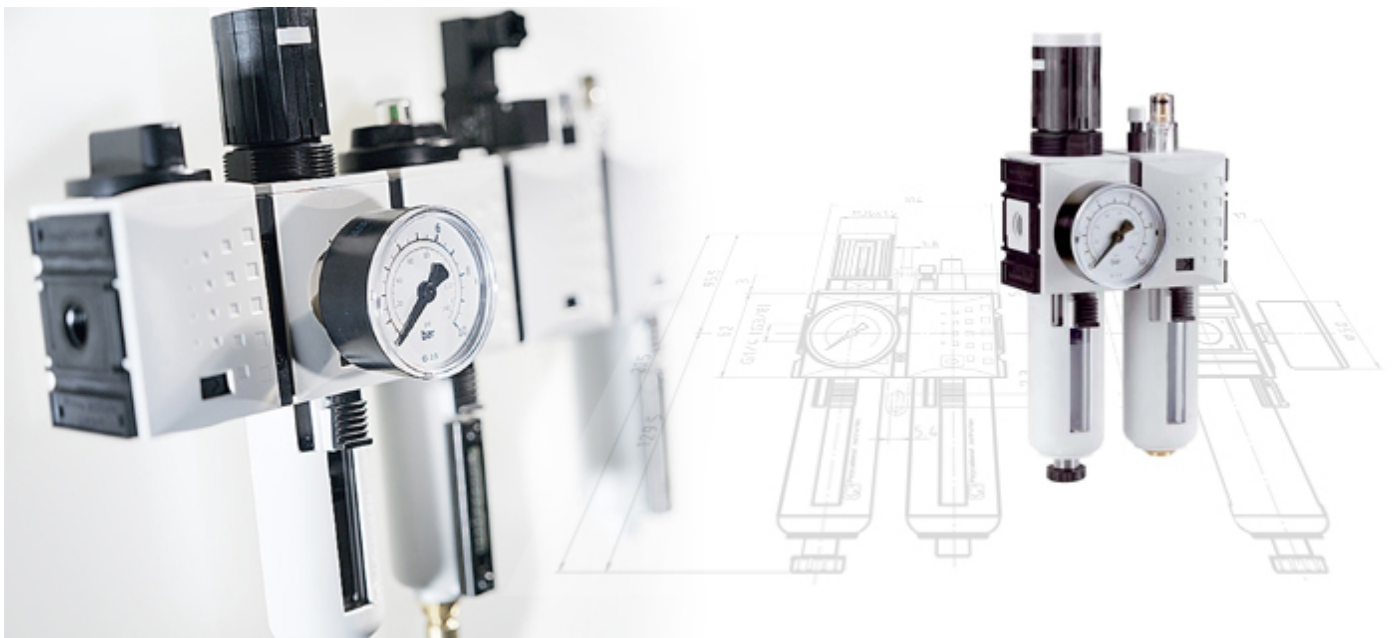
MultiFix



Standard



Classic



Further information can be found in the category "FRL-units" on our website.

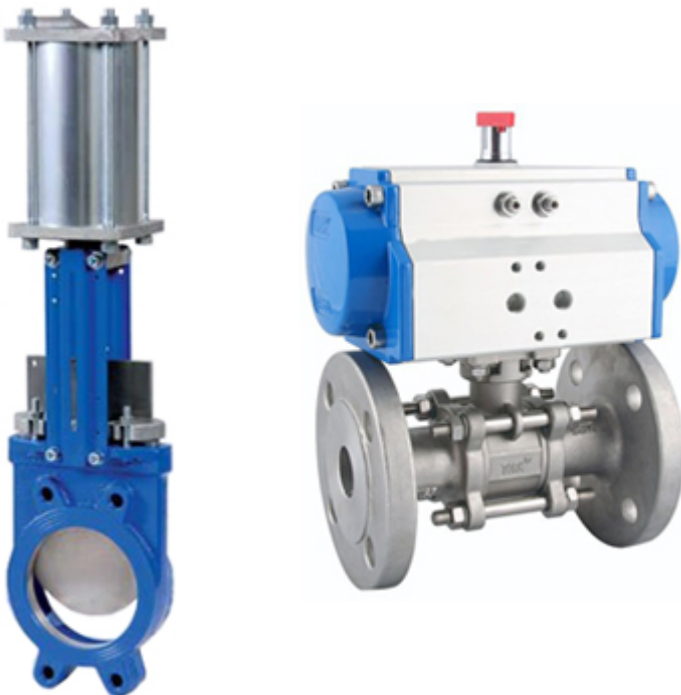
Chapter 11:

Valves and Actuators with the NAMUR-interface

Valves with NAMUR-interface to control process valves

1. Pneumatic actuation of process valves

Process valves can be actuated manually, electrically, pneumatically and hydraulically. **Often times pneumatic actuators** are in use when it comes to automated process valves. They are mostly either linear actuators (**pneumatic cylinders**) or **rotary actuators**.



Whether it's a linear or rotary actuator, the pneumatic automation of process valves is popular.

There are distinct advantages of pneumatic actuators in comparison to electric ones:

- High torque
- Low maintenance
- Few spare parts
- High durability
- High reliability
- Useable in explosion hazardous environments
- Inexpensive

As the field of applications and types of process valves is extremely wide, we will not cover that.

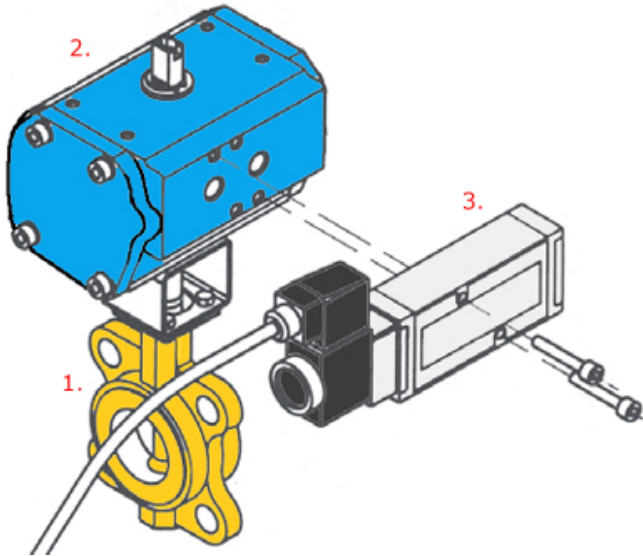
Instead we will focus on the **pneumatic actuation** and **control** of rotary actuators with **NAMUR-interface**.



A pneumatically automated process valve has three main parts:

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Valves and Actuators with the NAMUR-interface



1. Process valve

Part of the pipe-line system, e.g. ball valve or butterfly valve.

2. Pneumatic rotary actuator

Opens and closes the process valve.

3. Pilot valve (with NAMUR-interface)

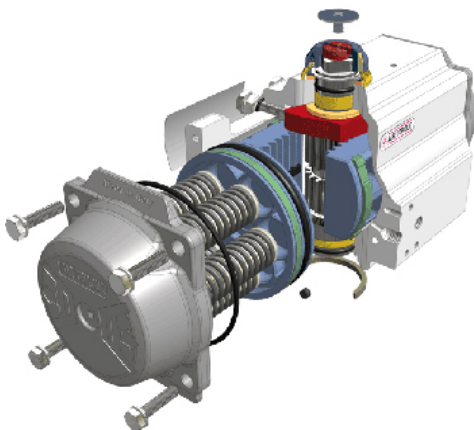
Directional control valve for control of pneumatic rotary actuators.

Further important elements can be:

- **Switch-box** to feed the position of the process valve back to a central command,
- **Manual override** – clutch for emergencies or
- **Positioner**, replacing the switch-box and mostly including the control valve.

2. Pneumatic rotary actuators

The design and dimensions of rotary actuators differ from manufacturer to manufacturer. The two most popular designs are either **Scotch-Yoke** or **Rack and Pinion** actuators. We will introduce you to the Rack and Pinion actuator with more detail.



The 2 piston rods of the 2 pistons inside the actuator are shaped like racks. Compressed air is driving them. The racks drive a pinion which is linked via a shaft to the process valve and opens or closes it.



The selected size of the actuator depends on the force required to open and close the process valve. Usually the manufacturer indicates the maximum torque the actuator offers at a specific pressure.

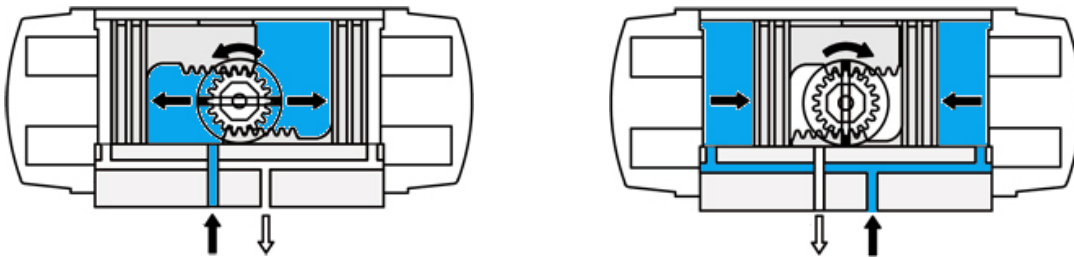
There are two versions of linear actuators:

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Valves and Actuators with the NAMUR-interface

- **Double-acting actuators**
- **Single-acting actuators** (with mechanic spring return)

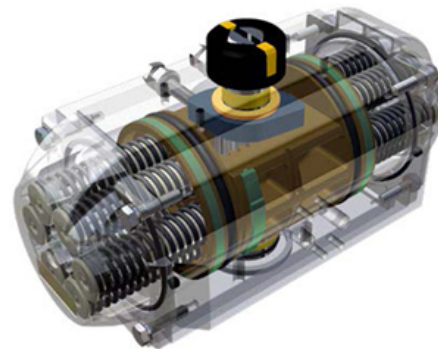
In **double acting actuators** - depending on the direction required - compressed air flows to the outside or to the inside of the two pistons. This can be easily controlled by **using 5-way directional control valves** (5/2-way for fully opening and closing the process valve, 5/3-way if intermediate positions are required).



In **single-acting actuators**, the reset to basic position is realized by using packs of mechanical springs.

Two packs of springs are positioned on the outside of the actuator, pushing the pistons into the middle position. The area the springs are in is called the **“spring chamber”**.

As soon as the actuation side of the actuator is exhausted, the springs push the pistons together, which turns the pinion and (depending on what is required) opens or closes the process valve.

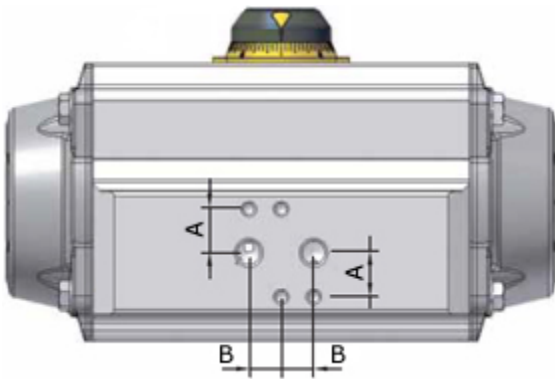


Chapter 11:

Valves and Actuators with the NAMUR-interface

There are standards for the contact interfaces of a rotary actuator, e.g.:

- Contact interface to the **control valve** | VDI/VDE 3845 (NAMUR)
- Contact interface to the **process valve** | ISO 5211 | DIN 3337



VDI/VDE 3845 (NAMUR)

Interface on the actuator that allows to flange directly a control valve with NAMUR-interface.



ISO 5211 | DIN 3337

Connection to the process valve.

Chapter 11:

Valves and Actuators with the NAMUR-interface



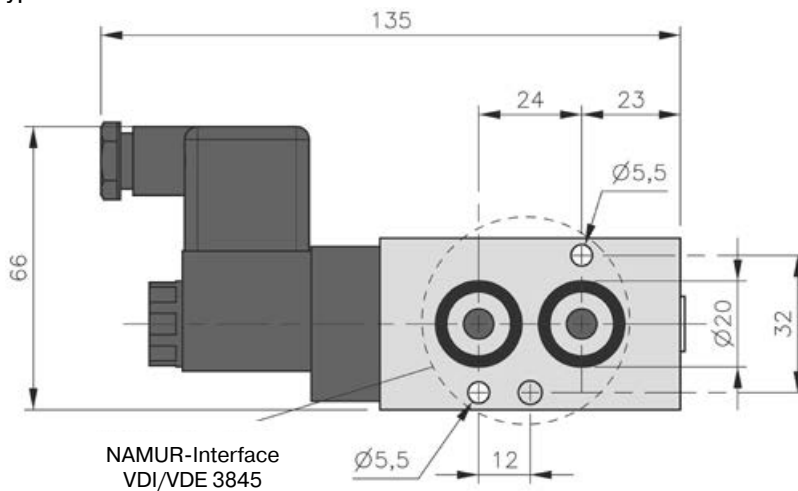
3. The NAMUR-interface

NAMUR-valves are **control valves** which offer **an assemblage interface according to the standard VDI/VDE 3845**.

NAMUR-valves are different from other in-line valves as they offer two ports on the flat side of the valve. In addition, there are holes for fixing the valve onto the actuator.

The drawing below shows a single solenoid 5/2-way valve with an interface according to NAMUR. The dimensions of the 1/4" -interface, among others, are shown as well.

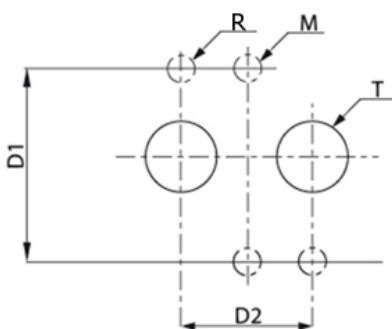
Type: **MNH 510 701**.



Besides the 1/4" -interface there is also one for larger actuators:

- **G 1/4"** - interface NAMUR valve | description: [NAMUR 1/4"] or NAMUR 1
- **G 1/2"** - interface NAMUR valve | description: [NAMUR 1/2"] or NAMUR 2

Dimensions of the NAMUR interfaces on the actuator



	T*	D1	D2	M
NAMUR 1/4"	G 1/8" / G 1/4"	32	24	M 5
NAMUR 1/2"	G 3/8" / G 1/2"	45	40	M 6

The hole **M** is typically used for mounting a setscrew onto the rotary cylinder, which fits into the blind bore of the valve and defines its operating direction.

The hole **R** is usually used for fastening screws.

Chapter 11:

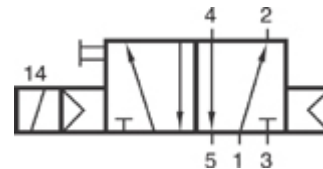
Valves and Actuators with the NAMUR-interface



The picture displays a **MNH 510 701**, which is a **5/2-way** single solenoid NAMUR-valve. It is used to control a double-acting actuator.

Ports **2** and **4** are on the side of the valve. The ports are sealed towards the actuator with O-rings.

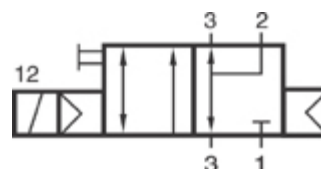
Port **1** (= supply) and ports **3** and **5** (= exhausts) are on the flat side of the valve (shown here on the top).



The picture displays an **MNH 310 701**, which is a **3/2-way** single solenoid NAMUR-valve. It is used to control a single-acting actuator.

Ports **2** and one port **3** are on the side of the valve. The ports are sealed towards the actuator with O-rings.

Port **1** (= supply) and the other port **3** (= exhaust) are on the flat side of the valve (shown here on the top).



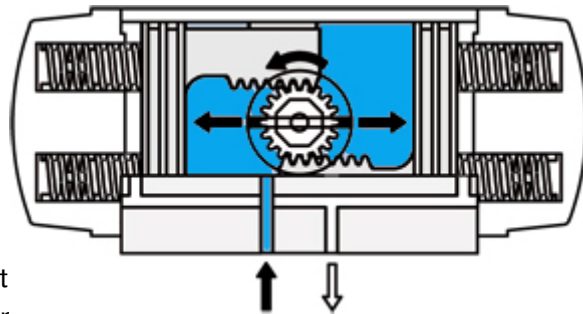
Chapter 11:

Valves and Actuators with the NAMUR-interface

A normal 3/2-way inline valve has 3 ports. The 3-way NAMUR-valve on the photo however has 4, which you can also see on its ISO symbol. WHY IS THAT?

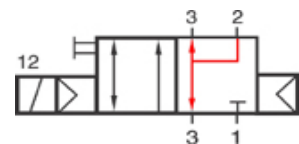
Single-acting actuators (the ones with springs) have 2 ports as well. One is connected to the **actuation side**, the other to the **spring chamber**.

In order to avoid air from the atmosphere (which might be wet, polluted or dirty) to enter the spring chamber, it should be ensured that (potentially cleaner) process air enters it instead in order to avoid corrosion of the springs.



That is why in process automation, we aim towards an **air recirculation** into the spring chamber, also called a **“purge”**.

When the actuation side of the actuator is exhausted (*3/2-way valve n.c. in standard position*), the actuation chambers are gradually becoming smaller and the spring chambers larger as the springs expand. The 3/2-way NAMUR-valve feeds part of the process air into the spring chambers before it is used to expand the actuation chambers. The excess air exhausts through the external (second) port 3. This function is indicated in red in the ISO symbol.



By feeding process air into the spring chambers, we want to reduce pollution inside the actuator due to dirt, dust, mist, moisture etc. that might have been sucked into the spring chambers and thus avoid corrosion of the springs.

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Valves and Actuators with the NAMUR-interface



4. HAFNER valves with NAMUR-interface

HAFNER Pneumatik offers a uniquely wide range of valves with **NAMUR-interface**, as well as **a range of accessories**.

- Solenoid valves | 3/2- (n.c. / n.o.), 5/2- and 5/3-way
- Pneumatically actuated valves | 3/2-, 5/2- and 5/3-way
- Hand lever valves | 3/2-, 5/2- and 5/3-way
- Everything mentioned above both in NAMUR 1 and NAMUR 2
- Numerous products made of stainless steel, for cold and for explosion-hazardous environments
- Flow-regulator plates
- Quick-exhaust valves and „purge-blocks“
- Numerous safety valves (manually, pneumatically or electrically actuated)
- Plates and accessories

HAFNER does not only offer standard products but also offers:

- **NAMUR Flex** | 5/2-way valve with a kit to convert it into a 3/2-way valve with air recirculation
- **Stainless steel** valves | made from 1.4404 (316L)
- **Low temperature** valves | -50°C to +50°C
- **High temperature valves** | -20°C to +80°C
- **BSP** or **NPT** ported
- **ATEX**-certified products for explosion-hazardous environment
- Specially selected materials | **brass-free** products
- Products with **air springs** or **combined springs**
- Products with swapped ports
- Products with different types of **manual override**

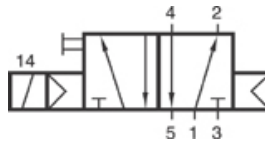
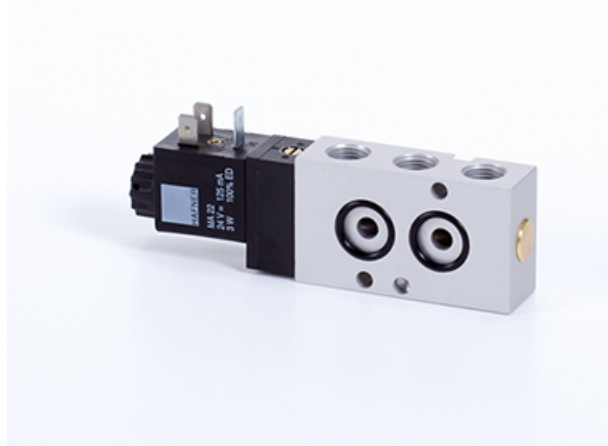
Chapter 11:

Valves and Actuators with the NAMUR-interface

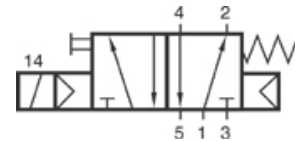


Values of the standard Hafner 5/2-way NAMUR-valve type MNH 510 701:

- Orifice size : **DN 7 mm**
- Flow: **1250 l/min**
- Operating pressure : **2 - 10 bar**
- Power consumption: **3 W / 5 VA**
(in combination with standard coil MA 22)
- Ports 1, 2, 3: **G 1/4"**
- NAMUR 1: **1/4"**



MNH 510 701



MNH 511 701

MNH 511 701: same valve, but with a combined mechanical and pneumatic spring return.

Standard sizes of HAFNER NAMUR-valves:

Series **701** | orifice: **7 mm** | flow: **1250 l/min** | ports: **G 1/4" – 1/4" NPT** | **NAMUR 1, 1/4"**

Series **101** | orifice: **10 mm** | flow: **2250 l/min** | ports: **G 3/8"** | **NAMUR 1, 1/4" → maximized air-flow**

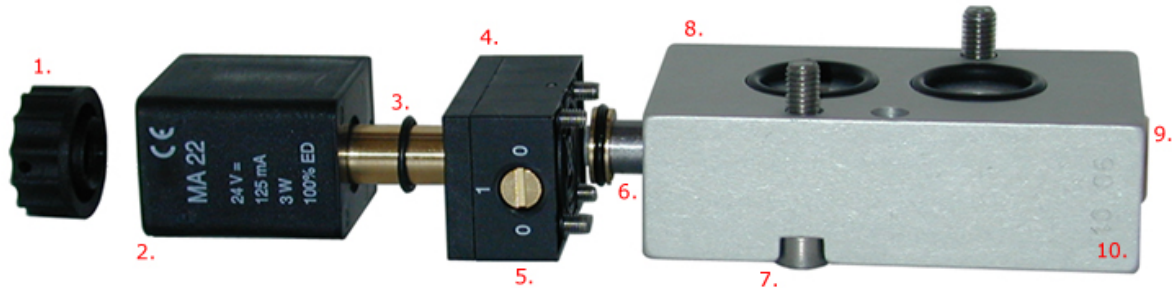
Series **121** | orifice: **12 mm** | flow: **3000 l/min** | ports: **G 1/2" – 1/2" NPT** | **NAMUR 2, 1/2"**

Conforming to standards, the flow measurement is shown as nominal flow in [l/min]. Nominal flow: at $p_1 = 6 \text{ bar}$, $\Delta p = 1 \text{ bar}$, stream-value of the compressed air (l/min).

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Valves and Actuators with the NAMUR-interface

Besides maximum flow of 1.250 l/min in a compact design there are 10 more competitive advantages of the Hafner NAMUR-valves series 701.



1. PA fixing nut, which protects the solenoid system from wetness and moisture.
2. Coil MA 22 fully covered with PA or Epoxy (on request), 360° rotatable. Others (Ex-versions) available on request.
3. Brass operator tube, including O-ring to protect solenoid system from wetness from the bottom.
4. Head made from PA.
5. Brass manual override for turning; other versions and materials (e.g. stainless steel) on request.
6. Spool made of stainless steel; other inner parts are: brass, POM, NBR, FKM.
7. Fixing screws, stainless steel.
8. Body, anodized aluminum.
9. End-cap made from brass.
10. Unique sealing system, the HAFNER swimming O-Ring.

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Valves and Actuators with the NAMUR-interface



5. Selection of Hafner NAMUR-Accessories

MNH 350 701: HAFNER NAMUR-Flex valve

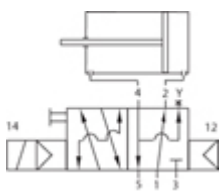
HAFNER's **MNH 350 701** is a single solenoid 5/2-way NAMUR -valve, electrically actuated with air spring return. It is used to control double-acting actuators (*with the same function as the MNH 510 701*).



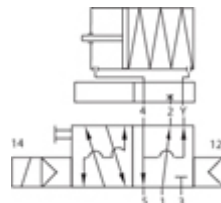
Adding the **Flex-Plate type FP 701**, the valve is converted into a 3/2-way NAMUR-valve with air recirculation for the spring chamber (purge).



The **MNH 351 701** offers a combined spring return.



MNH 350 701
works like a 5/2-way valve



MNH 350 701 + Flex plate
works like a 3/2-way valve

This valve is also available both in **stainless steel** and **NPT ported**.

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Valves and Actuators with the NAMUR-interface



DRN...: Flow regulator plates

The Hafner flow regulator plates offer a very precise control of the opening- and closing speed of actuators. Regulation possible with 3- way and 5- way valves.

Additionally the DRN offers the only possibility to regulate the forward- and backward-stroke of single-acting actuators, which is controlled by a 3- way valve, **independently and precisely**.

Two different types of actuation are available:

1. DRN_601: to be operated manually
2. DRN_611: to be operated with a screwdriver

Plates are available with 1/4" and 1/2" NAMUR-interface.

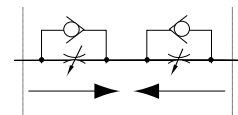
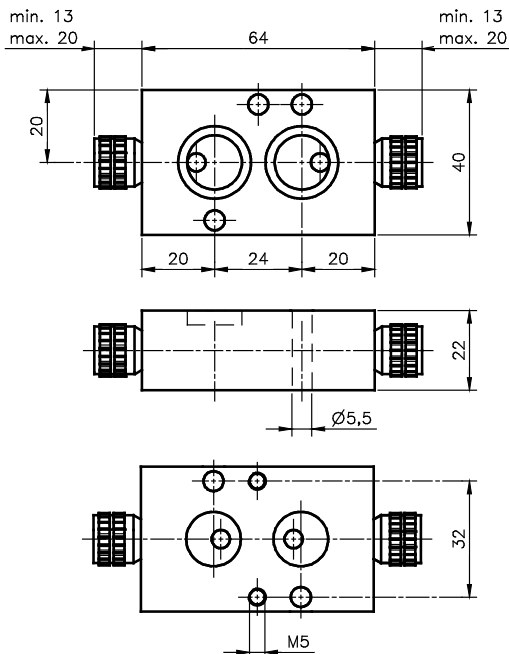
Assemblage between NAMUR pilot-valve and actuator or with threaded plate type GPN-1/4" for direct piping.



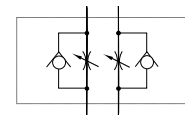
DRN 601



DRN 611



DRN 3 ... for single-acting actuators



DRN 5 ... for double-acting actuators

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Valves and Actuators with the NAMUR-interface

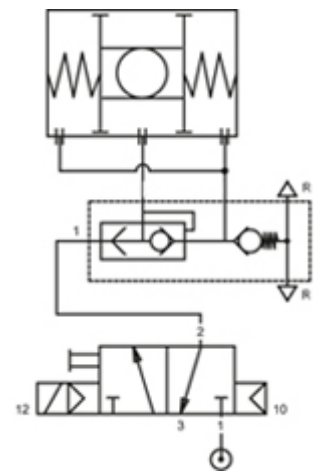


UB 701: NAMUR Air-recirculation block

The air-recirculation block guarantees, that only exhausting air from the actuation chamber is going into the spring chamber. No ambient atmosphere is sucked-in. It is used in combination with single-acting actuators when they get controlled by remote installed 3/2-way valves e.g. from a control cabinet.

The integrated non-return valve makes sure, that no ambient atmosphere can enter the actuator.

Block is designed for actuators with 1/4" NAMUR-interface. Port 1 for air-pressure supply G 1/4" threaded. 2 x G 1/4" exhaust ports.



Further information about our NAMUR-valves and accessories can be found in our catalogue "Competence in Valve Automation".

