Didactic Handbook

MODERN PNEUMATICS

Components for Pneumatic Automation

didactic

PNEUMAX GREEN LINE: TECHNOLOGY & INNOVATION

PNEUMAX®

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Chapter 4

PRESSURE MEASURING DEVICES

4.1 MANOMETERS OR PRESSURE GAUGES

Industrially, gauge pressure is measured with instruments called manometers, of which the most used one is the Bourdon. It is based on the elastic deformation of a tubular metal spring with lens section, folded in a semicircular shape and subjected entirely to the pressure exercised by the fluid.
An end of the spring is open, and after having fixed it to an externally threaded sleeve in order to fasten the instrument, it remains connected to the fluid of which we want to measure the pressure.
The other end is closed, and is free to move under the action of the fluid that presses against it internally, and therefore tends to straighten it out causing a movement of the closed end that is proportional to the applied pressure.
By means of the engagement with a sector roller, the movement of this non bonded end is amplified in such a way that an indicator fixed on the roller's axis shows the pressure value.

Bourdon Manometer

Chapter 6

PRESSURE

6.1 Pressure

6.1 PRESSURE

Pressure is indicated with a “p” and is the physic magnitude that expresses the distribution of a force on the surface on which it is applied.
Its value is determined by the force that acts statically on a surface unit.
Therefore, pressure p is a force F exercised perpendicularly by a fluid on the surface unit A of a body and this means:

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

In the SI system, the pressure is measured in N (Newtons) per m^2, and the name Pascal (Pa) is assigned to this unit

$$1\ Pa = \frac{1\ N}{m^2}$$

Actually, Pa being a very small measuring unit, we generally use its multiples, such as kPa.
Currently, the bar is still used and admitted by the IS system, as a pressure measuring unit.

$$1\ bar = 10^5\ Pa$$

In Anglo-Saxon countries, the measuring unit used is psi (pound/inch2):

1 psi = 0,07 bar
14,5 psi = 1,00 bar

The following table compares the different measuring units used as pressure measuring units.

Pressure	kPa	bar	psi	kg/cm²
1 kPa	1	0,01	0,145	0,102
1 bar	100	1	14,5	1,02
1 psi	6,9	0,069	1	0,07
1 kg/cm²	98	0,0981	14,2	1

Except for any different prescriptions, by fluid power we always mean the relative pressure whenever we refer to the operating pressure of any equipment or system.

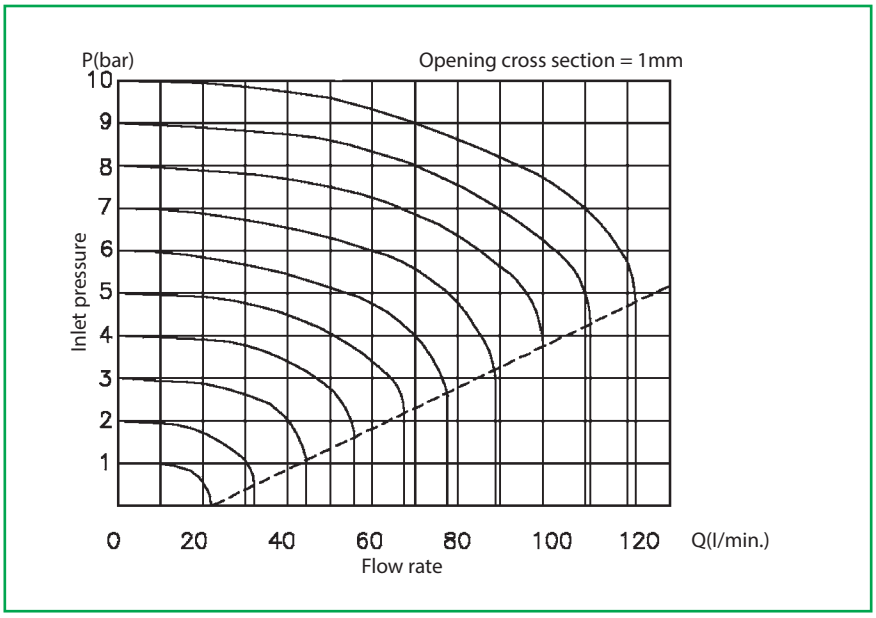
Being the speed u expressed in m/s and the area in m^2, we shall have:

$$\frac{m}{s}\ m^2 = m^3/s$$

In the SI, the measuring unit of the flow rate is m^3/s, and it may be expressed also in l/s (liters per second) where

$$1\ l/s = 1\ dm^3/s$$

Calculation of a gaseous fluid's flow rate is difficult because its speed involves many parameters due to its compressibility.
The following diagram shows the ratio between pressure and flow rate during its passage through a 1 mm^2 section hole.



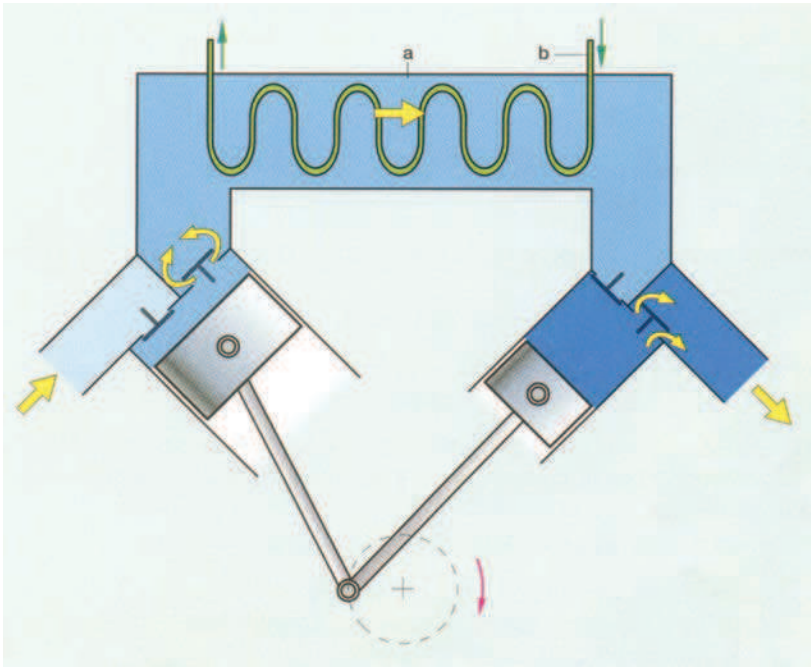
The area delimited by the dotted line highlights the area where the air reaches a very high speed, that is close to the speed of sound (sonic stream), a speed that cannot increase even if the difference of pressure should increase.
Within this area, the curves adopt a vertical run.
With a difference of pressure equal to zero between inlet and outlet, we shall have no flow rate. Introducing ΔP we shall notice a flow rate that shall be as high as great the ΔP is. Air in fact shall flow increasingly faster across the hole until its speed equals about 340 m/s, as the speed of sound.
From this moment onward every increase in ΔP shall produce no flow rate increase since the air has reached its maximum speed.
For example, with an inlet pressure equal to 6 bars and an outlet pressure equal to 5 bars (ΔP=1 bar), from the diagram we can notice a flow rate of about 55 l/min for a section equivalent to 1mm2.

9.2 TYPES OF COMPRESSORS

Reciprocating compressors are divided into two categories: piston and membrane compressors.
Piston compressors are employed in the greater part of pneumatic applications, while the second ones, membrane compressors, do not have much importance and are only used in certain simple hobby applications.
Volumetric rotary compressors come in three types: gear or lobe, vane and screw compressors.

Reciprocating piston compressors

They adapt to the generation of low, medium and high pressures.
Multistage compressors are used to generate high pressures.

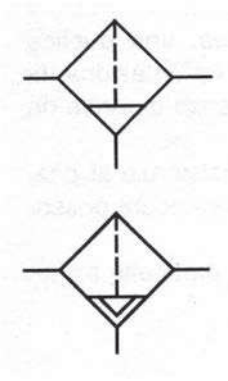


Up to	**1 bar**	**mono-stage**
Up to	**15 bar**	**two-stages**
Over	**15 bar**	**three or more stages**

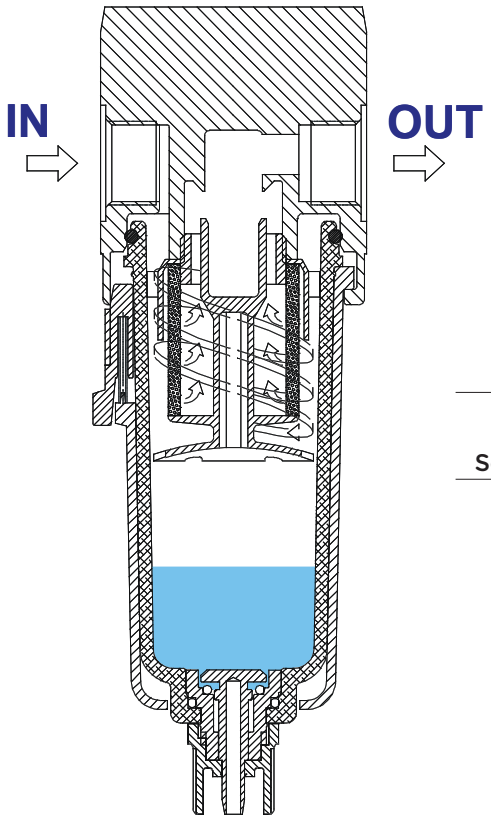
The operating principle is based on a system including a cylinder and a piston that flows alternatively inside it, activated by a rod and crankshaft transmission.
Two valves on the cylinder's head control air flow during suction and compression.

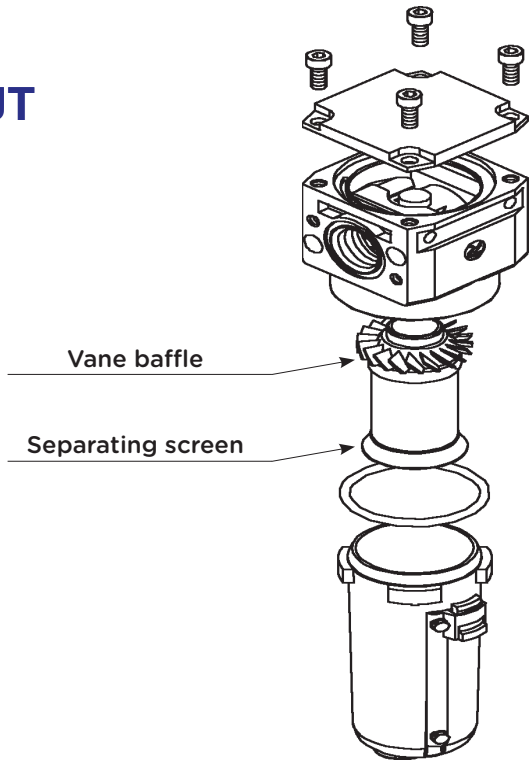
It is known that air does not contain only water vapor, but also solid particles and degraded oil vapors produced by the compressor, etc.
The task of any filter, at the user's point, is to clean the air completely from the moment it is placed in-line, after the suction and line filters have carried out the first rough filtering.

Manual drain

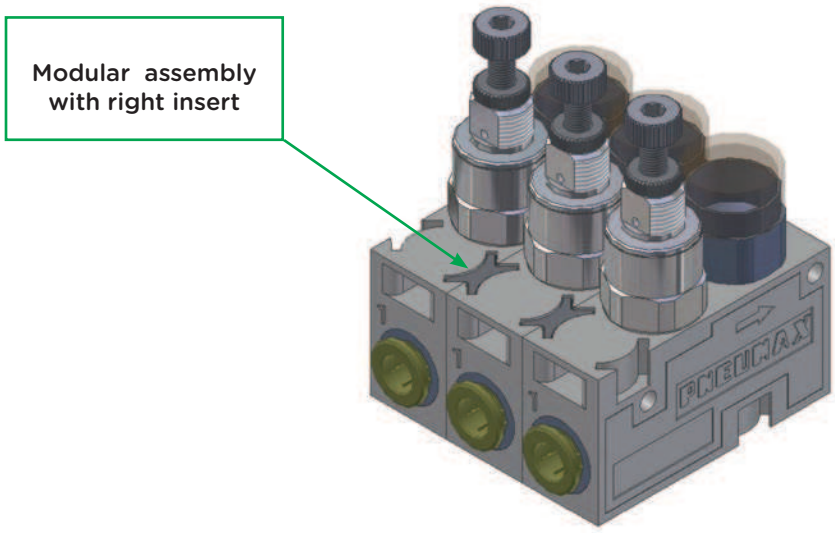


Automatic drain



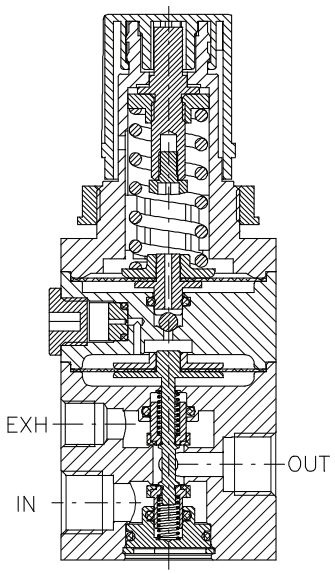


Even in miniaturized versions, similar solutions that include the modular assembly system with its own incorporated pressure indicator are possible.



Precision regulators

Precision pressure regulators guarantee maintenance of the set-up secondary pressure at an almost perfect value, if their performance is kept within the limits recommended by the technical datasheet.
Its operation is based on the same principle of standard regulators, with the difference that control of the secondary pressure is assigned to a double membrane system. The first membrane in the upper part, pushed by the spring, intercepts an air leak (5 Nl/min) by means of a sphere on a calibrated hole.

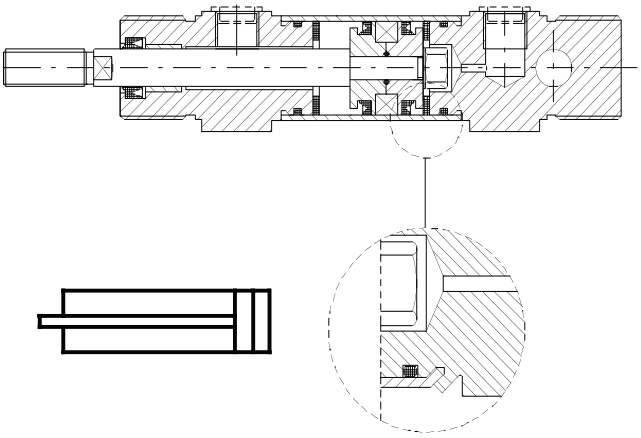


Chapter 12

FITTINGS

FITTINGS, TUBES AND QUICK COUPLINGS

Pneumatic circuit components are connected to each other by means of fittings, which are tubes that transport the signals and feed the valves and actuators.



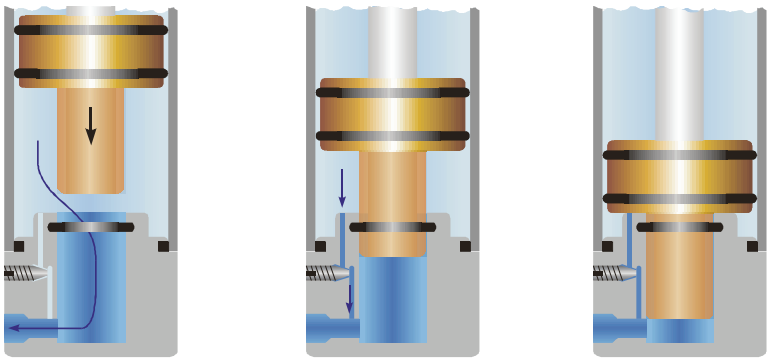
Cushioned double-action with elastic/rubber bumper

The figures show two different systems for absorbing the final kinetic energy, in order that the covers may not suffer any damages during impact.
The most effective system is made of an air-cushion that slows down the piston's stroke in the last centimeters. In small cylinders, or when the speeds involved are not high, spring washers may be used at the sides of the piston. The strokes in double-acting cylinders may be considerably large, providing that they are compatible with the mechanic application.

13.5 AIR-CUSHION ABSORBER

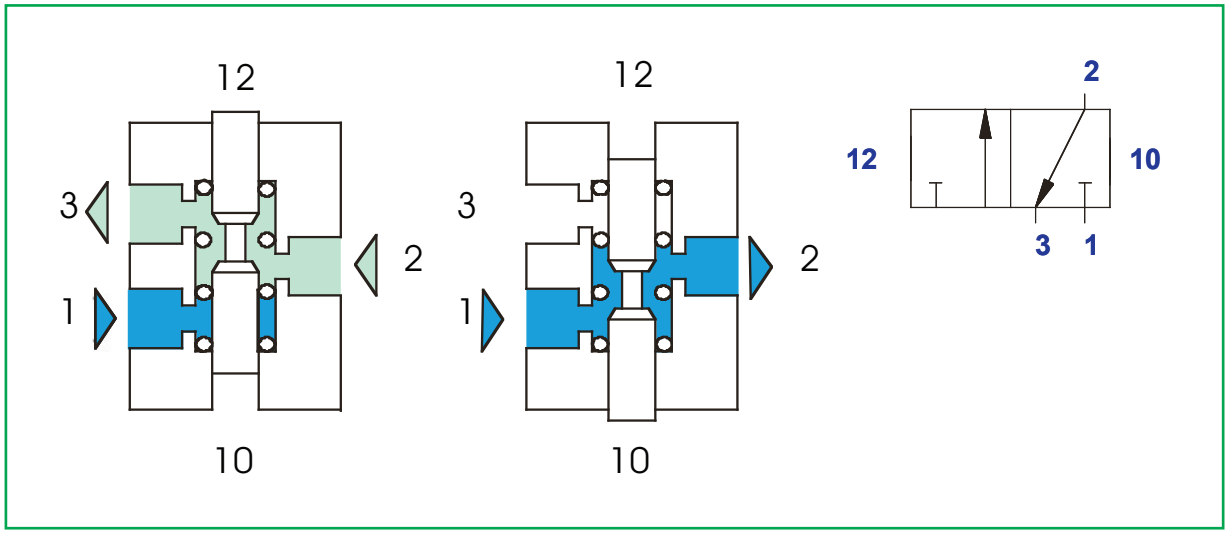
Pneumatic cylinders are able to produce high speeds, and therefore, the impact forces at stroke end may be considerable.
As previously said, the impact of the stroke limiter (adjuster) is tempered using an air-cushion that reduces piston speed near the end of the stroke.

Air-cushion absorption adjustment



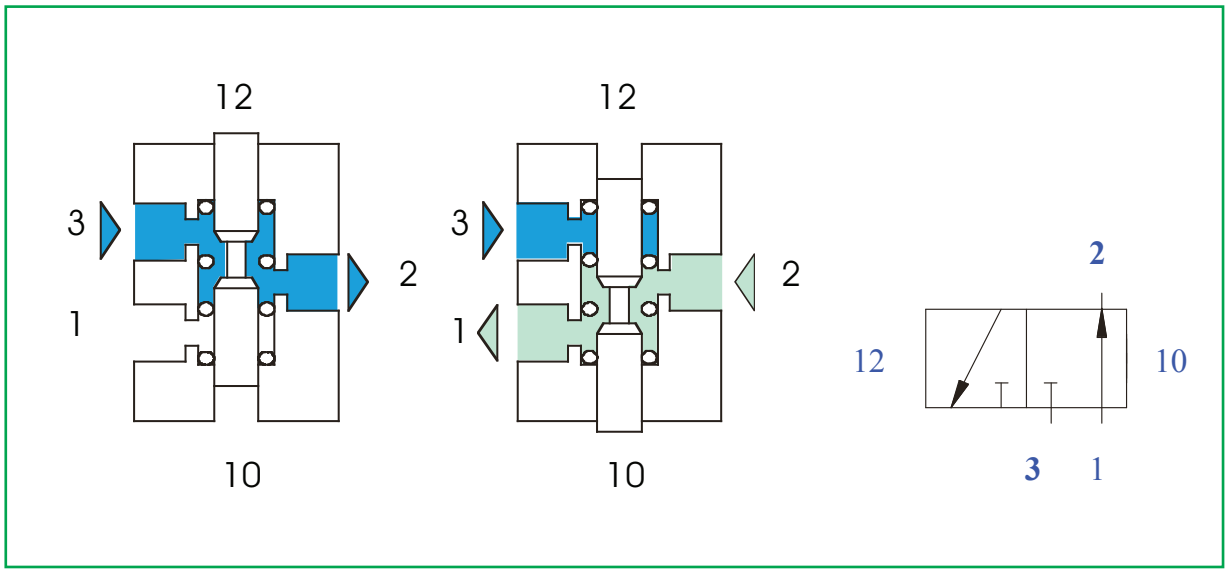
activating forces needed to commute the valve are always the same independently from the operating pressure. For this reason, they are called balanced spool valves.

3/2 N.O.



In the case of balanced spool valves it is possible to transform them from normally closed to normally opened by simply reversing both the feeder and the exhaust, and it is also possible to transform it into 2/2 by closing exhaust 3 with a plug.

5/2



Also in this case, the left figure shows the valve in its rest position and the right figure shows it in its working position. We can see the separated exhausts for each outlet, with exhaust 3 dedicated to outlet 2 and exhaust 5 dedicated to outlet 4.
When discharge 2 is under pressure, outlet 5 is in discharge and vice versa.

Ohm's law

Ohm's law says: voltage is equal to the product of the current by the resistance.

$$V = R \times I$$

Knowing two values of the just mentioned ratio, we can calculate the unknown value simply.

$R = U / I$	calculation of resistance knowing voltage and current
$R = V^2 / W$	calculation of resistance knowing voltage and power
$I = V / R$	calculation of current knowing voltage and resistance
$V = R \times I$	calculation of voltage knowing resistance and current
$W = V \times I$	calculation of voltage knowing resistance and current
$W = R \times I^2$	calculation of power knowing resistance and current
$W = V^2 / R$	calculation of power knowing voltage and resistance

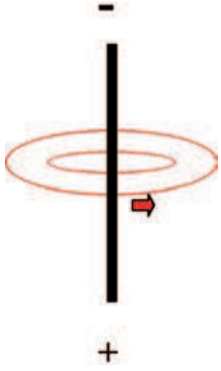
R = Resistance expressed in Ohms
I = Current intensity expressed in Amperes
V = Voltage expressed in Volts
W = Power expressed in Watts

Magnets

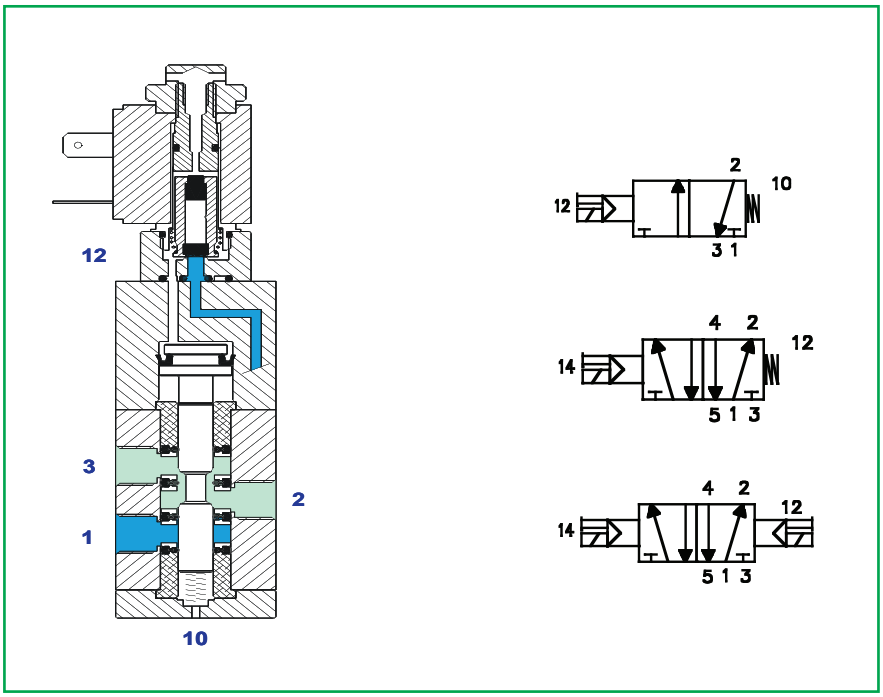
If an iron bar is exposed to a high magnetic field during a period of time, it also becomes magnetized. This phenomenon is called permanent magnetism, and is the ability of the iron bar to attract other objects made with the same material. Magnetic force lines may be easily visualized with some iron filings on a paper sheet placed over the magnet. The magnet has a north pole and a south pole. In fact, if we hang a magnet from a thread, one of its ends shall always point north, and this shall be the magnet pole defined as North Pole. Opposite poles attract, equal poles repel. If two magnets are placed in series with each other, the magnetic field shall be equal to the one generated by a single magnet of the same size.

Electromagnetism

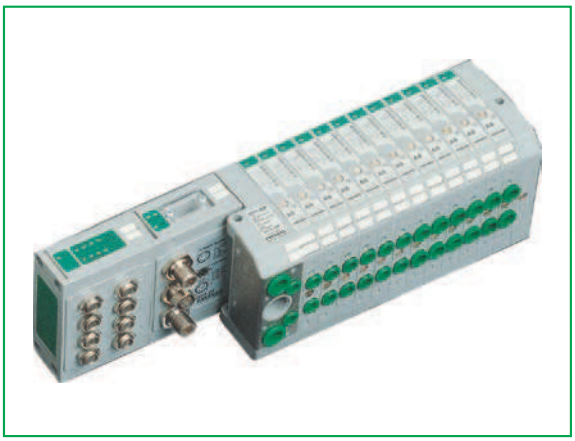
Electric current and magnetism are strongly correlated, because if a cable is run across by an electric current it generates a magnetic field, which must be seen as a series of force lines that create concentric rings closed around the thread.



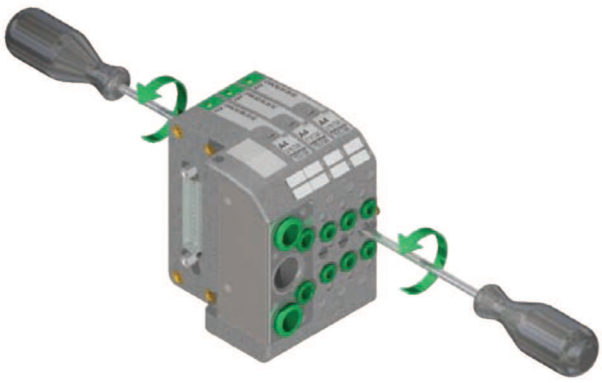
We should involve large forces in order to be able to reach ample flow rates because, with high transition sections, Fp should have a outstanding capacity as well as Fm, that opposites it. Consequently, the sized coil shall have a higher power. This limits the equipment that therefore results suitable for poor flow rates. Therefore, for higher flow rates we must avail ourselves of a system that may exaggerate the air flow. A direct-acting electro valve shall be used as a controlling or steering element, and a pneumatic valve shall be used as the exaggerating element.
Combining these two elements in only one unit we shall obtain an **indirect-acting** electro valve.



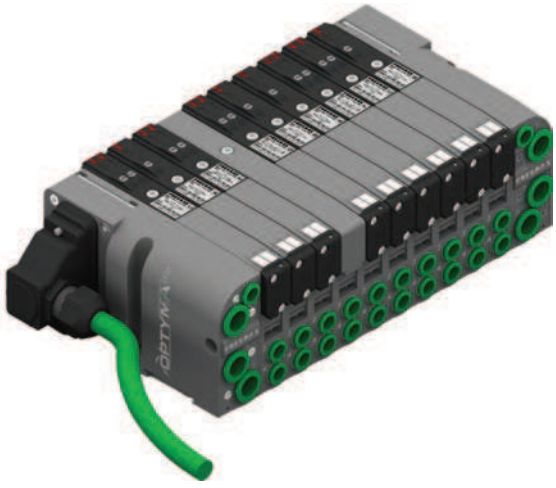
Monostable, bistable, 3-ways or 5-way, 2-position or 3-position electro valves may be obtained this way.
Automatic systems require increasingly equipment with reduced dimensions and high performances, and that may interface with electronic controlling systems: therefore low electric consumptions are a very important perquisite.
As all electric components, electro valves are also subjected to standards that determine their protection.
The devices' protection degree is determined by the type of electric connection to the coil. The international standards that regulate it are I.E.C. 144. However, there are also national standards, as for example the Italian C.E.I. and the German D.I.N. The international abbreviation that identifies the protection degree is made up by the initial abbreviation IP and by a two-digit number of which we will now proceed to explain its meaning.
The first digit defines the protection against any accidental contact with solid bodies and the second one against water seepages.
The standards for electro valves are generally IP40 and IP65.



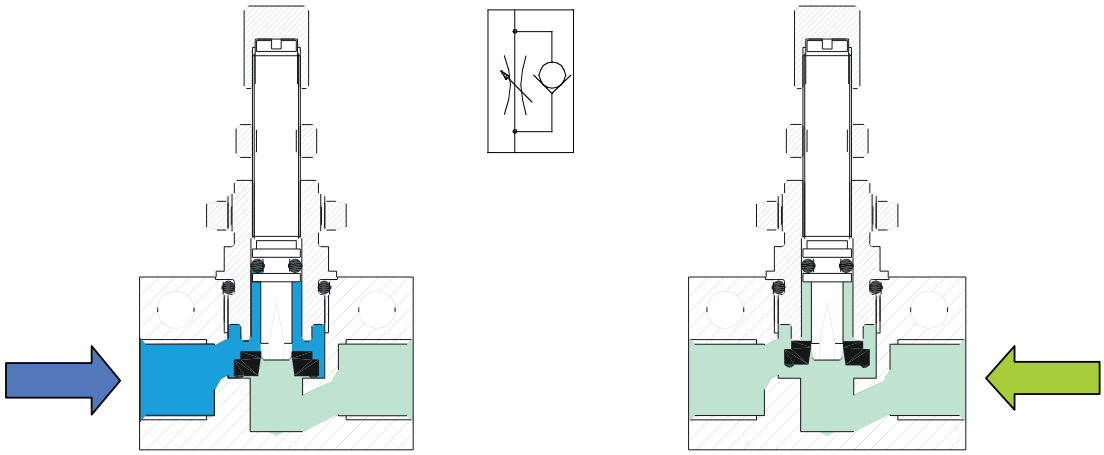
Batteries such as the one illustrated in the in figure, embody solutions for complex problems, and are extremely easy to use, offering the possibility of pneumatic and electric expansion obtained thanks to careful product design.



In fact, with a simple screwdriver it is possible to add a new “sliver” and expand the battery without any difficulty.



There are two types:
- Unidirectional
- Bidirectional

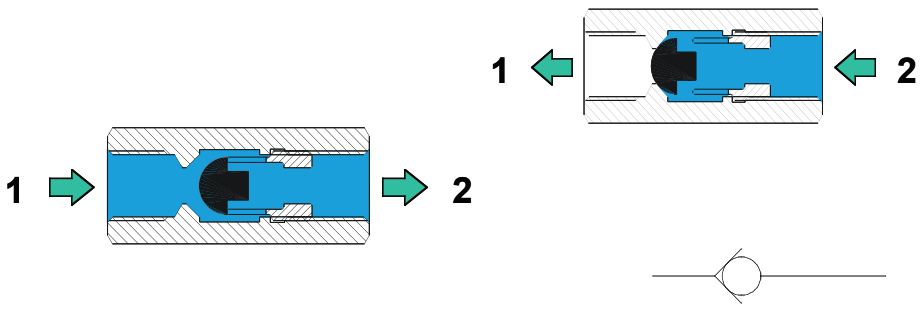


Regulated flow **Free flow**

The symbol represents very well the regulating operation and shows the parallel variable throttle to a non-return valve. The flow is regulated in one direction, while in the opposite direction it raises the unidirectional valve and flows freely. It is mounted in the connecting ducts between valve and cylinder. In the control valves for double-acting 5-way cylinders, variable reducers that may perform the same function of the unidirectional flow control valves may be mounted on exhausts 3 and 5.
If the non-return valve is stopped in the position indicated in the regulated flow figure, it shall be deactivated, and the air flow shall be subject to regulation in both directions (bidirectional).

15.2 NON-RETURN VALVES OR UNIDIRECTIONAL VALVES

The function of the non-return valve is to make the air flow in a single direction and to prevent it from flowing in the opposite direction.



These systems are possible only if these protocols are defined in a clear, precise and well documented way.
At the end of the '70s, ISO (International Standard Organization) recognized a standardized method for defining communication protocols, and it started the Open System Interconnection (OSI) project with the purpose of defining a reference model to develop protocols oriented to the interconnection of open systems. The final result was the definition of the OSI Basic Reference Model as standard ISO 7498.

Owner's standard protocols

Starting with OSI as a reference model, ten fieldbus that are different from each other have been created. Some of these have been established in the market and have become standards. In a system that uses a standard protocol, even if the nodes are produced by different sources, they may communicate with each other easily. There is nothing that prevents a producer to plan and generate a protocol based on his own needs, but it surely prevents the use of nodes from other producers in the Fieldbus system.
In the compressed air automation sector with, electro valve batteries are integrated to the node, and using the main standard protocols it is possible to insert them into the network together with devices having other functions, under the condition that the protocol used is the same one. The main standard protocols are:

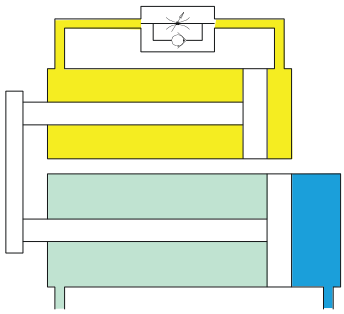
- **Interbus®**
- **Profibus®**
- **CANopen®**
- **DeviceNet®**
- **AS Interface®**

Standard protocols are different from each other due to certain technical features such as:

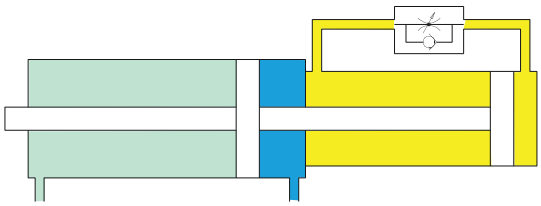
- Network type
- Communications methods
- Transmission speeds
- Number of participants, including the master
- Network length
- Transmission means

Before illustrating the main fieldbus features, let us explain the meaning of certain terms that we will find herein later.

Nodes: Devices that make up the network
Master: A device that controls the fieldbus (PLC, PC, dedicated cards etc.)
Slave: A device equipped with outputs that receives controls by the master and transfers them to the actuators (valves, motors, lamps etc.). If it has inputs, it sends the information sent by the sensors (buttons, stroke limiters, etc.) directly to the master.
Repeater: An amplifier that allows improving network electric signals in order to cover larger distances.

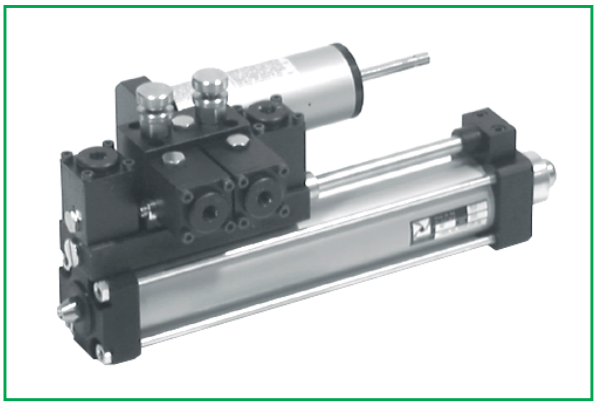


Parallel Connection



Serial Connection

The two figures show the device connected to a pneumatic cylinder in a parallel or a serial version. During its motion the pneumatic cylinder drags the rod of the brake full of oil, which transfers the fluid from one chamber to another one transiting across a flow regulator.
Therefore, the speed of the pneumatic cylinder is controlled with a non-compressible fluid removing the inconvenient previously described. The figure shows the operating principle schematically which shall actually be completed with a series of other accessory valves able to control the speed, the intermediate stops, as well as to reach the maximum speed in one direction or in both directions. Moreover, the device shall be equipped with an additional tank in order to allow compensating the difference of volume of the two chamber brakes due to the presence of the rod.



The obtainable combinations include many options and they are described with their own symbols. The device cannot be used alone because it does not have the ability to produce a motion on its own; it must be connected mechanically anchoring its own rod to the one of the cylinder. The figure illustrates a parallel brake with all the functions to stop, skip (maximum speed) and speed regulation, all in both directions (complete conformation).
It is possible to have this kind of devices integrated with a pneumatic cylinder. This however will impact on available space.

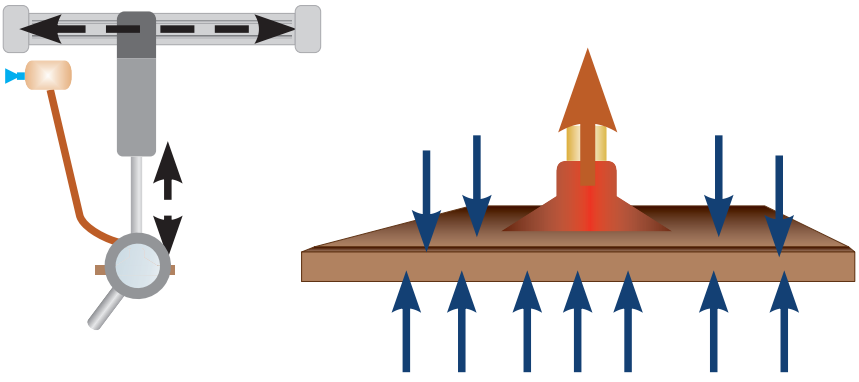
Vacuum is employed in three main fields:

- Blowers or rough/low vacuum (from 0 to -20 kPa) for ventilation, cooling and cleaning

- Industrial vacuum (from -20 to -99 kPa) for lifting, handling and automation

- Process vacuum (-99 kPa) high vacuum for laboratories,
microchip production, coverings with molecular deposits, etc.

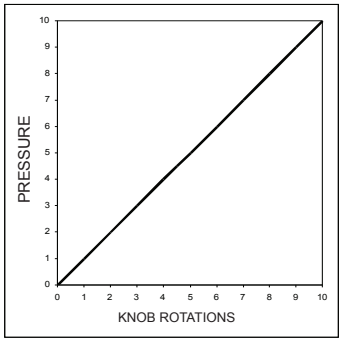
Vacuum is created by means of mechanical pumps, which may be suction or blowing and volumetric pumps, or of pneumatic pumps such as single-stage ejectors or multi-stage ejectors.
Suction or blowing pumps produce a low vacuum while volumetric piston or vane pumps are used to produce industrial vacuum with important flow rates.
Pneumatic pumps use compressed air as their feeding source, and are based on the Venturi effect principle, creating a depression.
Vacuum generators with Venturi effect offer many advantages: a simple and competitive method, no wear problems (absence of moving parts), reduced size and the possibility of being directly assembled on mobile and compact means such as robotized systems. This solution allows reducing the length of the tubes and improving response times. There are two types of generators: single-stage and multi-stage. In the single-stage version, the feeding air crosses only a Venturi's nozzle before being ejected and creates a depression on the junction of the intake circuit. In the multi-stage version, the air crosses two or more nozzles connected in series, ensuring a greater suction flow rate in the intake circuit. The feature of this equipment is the possibility to have, at the start of the suction, an abundant flow rate with reduced depression, and this allows reducing depression times. It is advised for large systems. A vacuum level equal to -92 kPa may be reached. These systems may satisfy the most varied needs for the vacuum control, since they may be integrated perfectly to grip and move a great number of objects, in many sectors of industrial activities.



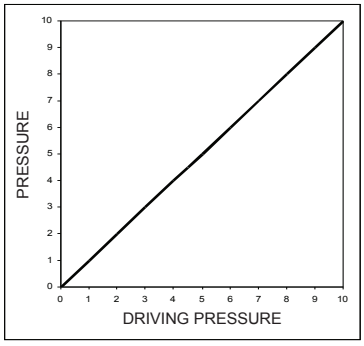
Regulation types

The feature of a proportional valve is to supply in exit a proportional signal to a reference signal.
This signal may be produced mechanically, such as pressure reducers that are activated by the force produced by the compression of a spring, pneumatically, sending a pressure signal in piloting as for remotely controlled reducers, or electrically with modulated voltage or current signals.

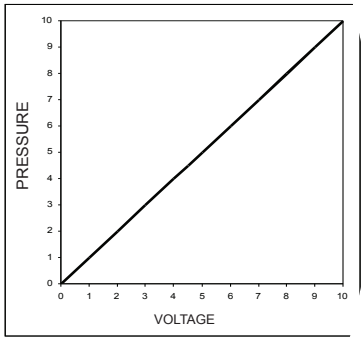
Mechanic



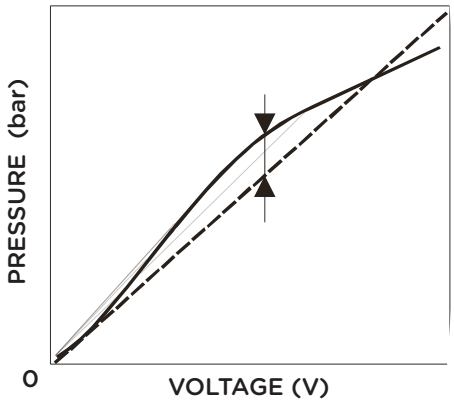
Pneumatic



Electric



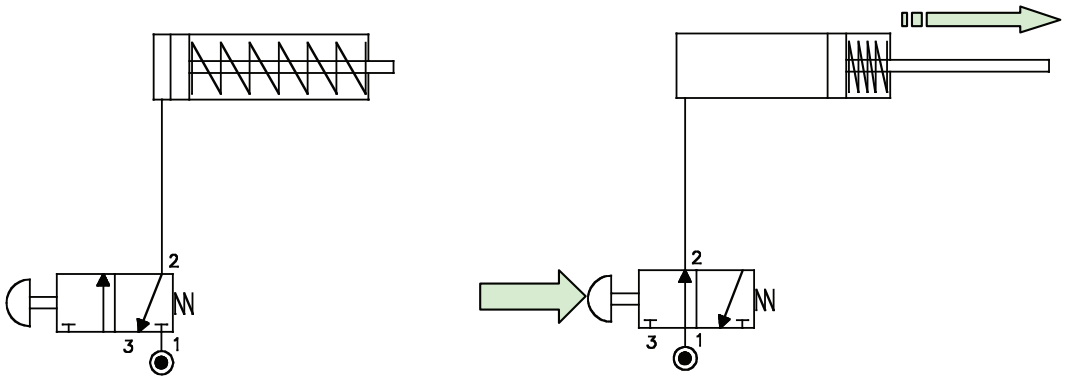
The diagrams show the running of the outlet signal, comparable to a line, according to its running in inlet. In industrial applications, the most used regulation is the electric one, managed by electronic cards which produce the signal.



The diagram shows the assimilation to the line.

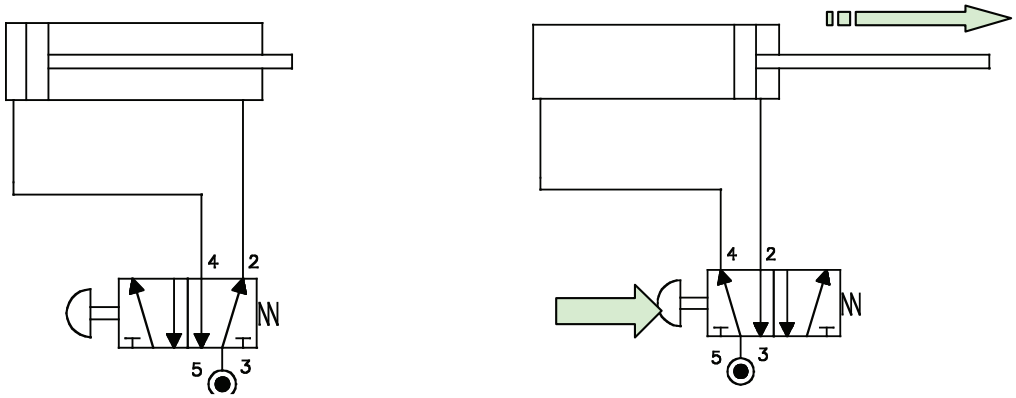
21.1 ELEMENTARY CIRCUITS

The situation of the most simple circuit connection is represented by the direct control of a single-acting cylinder.



At resting position Active

A 3/2 manual control valve activates the cylinder, connecting outlet 2 with the cylinder's inlet port directly. The back chamber of the cylinder, from its resting position, is discharger by means of way number 3 and the feeder in 1 is intercepted. Activating the manual control, 1 is connected to 2 and the cylinder is fed. This is the connection for direct control of a double-acting cylinder.



At resting position Active

IIn this case, the cylinder's resting position is not kept by the return spring but by the compressed air which feeds the cylinder's front chamber.

PNEUMATIC "AIR TREATMENT" SYMBOLS

AIR SERVICE UNITS

Air treatment mechanisms	Other mechanisms
Pneumatic accumulator (capacity)	Pressure gauge
Automatic drain air	Shut-off valve
Automatic drain air	
Lubricator	Progressive start-up valve With Electric control
Air filter	
Filter - with manual drain	
Filter - with automatic drain	
Pressure control valves	Progressive start-up valve With Pneumatic control
Pressure switch	
Free discharge pressure relief valve	
Free discharge pilot-operated pressure relief valve	
Sequence valve	
Pressure regulator	
Pressure regulator without exhaust valve	
Pilot-operated pressure regulator without exhaust valve	
Pressure regulator without exhaust valve (free)	
Differential pressure regulator	
Assembled units	
Filter pressure regulator	
Filter pres. reg. + lubricator Filter + pres. reg. + lubricator	

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