Didactic Handbook

MODERN PNEUMATICS

Components for Pneumatic Automation

didactic

PNEUMAX GREEN LINE: TECHNOLOGY & INNOVATION

PNEUMAX®

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MODERN PNEUMATICS

INTRODUCTION TO THE PRINCIPLES OF COMPRESSED AIR

PRELIMINARY REMARKS

An in-depth look into automation of products / systems, from small to larger industry, pneumatics offers support for quick, economic and functional solutions of both simple and complex problems.

Until now, pneumatics is the most frequent used application intermingled with electronic technologies, due to its large variety of components (lightweight properties, safety, reliability, compatibility with other technologies, etc.).

Although some limits to pneumatic components do exist, a balanced approach is necessary to identify performances that may not be possible and at the same time focus on the real possibilities that pneumatics can offer.

By means of this training manual we intend to introduce knowledge, trusting that it might stimulate and help to grow further knowledge of pneumatic solutions.

WARNING

Improper use of the products described in this catalogue may be hazardous to people and/or property.

The technical information described for each product in this catalogue may be subjected to change at any time; the company reserves the right to make manufacturing modifications without prior notice.
All products included in this catalogue, as well as its information and technical characteristics and specifications, must be examined and studied by a technical representative of the company using the product, ensuring that the product is in accordance to the application for which the product has been designed. In particular, the users shall assess the operating conditions of each product according to how it shall be used, analysing the information, as well as its technical qualities and specifications in view of the specific applications, and ensure that all the conditions regarding the safety of people and/or property shall be considered while the product is being used. Should the user have any doubt, contact our technical office.

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The user shall always be in charge of validating the applications.

The information mentioned may be subjected to modifications without prior notice.

Chapter 1

"SI" INTERNATIONAL UNIT SYSTEM

1.1 SI BASE UNITS

The SI international system is a system that values all physical magnitudes by means of measuring units, technically established and internationally accepted.
It is based on seven base units (see table) from which the units of all the other magnitudes are a consequence.

MAGNITUDES	SI UNITS		ADMITTED UNITS		RATIOS
	NAME	SYMBOL	NAME	SYMBOL	
Length	meter	m			
Mass	kilogram	kg	Gram Ton	g t	1 g = 0,001 kg 1 t = 1000 kg
Time	seconds	s	minute hour day	min h d	1 min = 60 s 1 h = 3600 s 1 d = 86440 s
Electric current intensity	ampere	A			
Temperature	Kelvin	K	Celsius degrees	°C	0 °C = 273,15 K
Brightness	Candela	cd			
Quantity of material	mole	mol			

1.2 DERIVED UNITS

The accepted units related to the pneumatics sector are described in the following table.

MAGNITUDES	SI UNITS		ADMITTED UNITS		RATIOS
	NAME	SYMBOL	NAME	SYMBOL	
Force	Newton	N [kgm/s^2]			
Pressure	Pascal	Pa [N/m^2]	bar millibar	bar mbar	1 bar = 100000Pa 1 mbar = 100Pa
Work, Energy Heat	Joule	J [Nm]	kilowatt-hour	kwh	1 kwh = 3,6 MJ
Power	Watt	W [J/s]			1 W = 1 J/s
Frequency	Herz	Hz [1/s]			
Volume	cubic meter		l Liter	m^3	1 l = 1 dm^3 1 m^3 = 1000 l

In some applications, the force is still expressed in kp (kilopond).
The N (Newtons) are now used commonly; please see below the ratio between the two magnitudes:

1 N = 0,102 kp
1 kp = 9,81 N (approximately 1 kp = 10 N)

In fact, the acceleration in a material point is equal to: $\mathbf{a = \frac{F}{m}}$

Where:
F = force acting on the material point, is expressed in N
m = mass of the material point, is expressed in kg
a = acceleration in m/sec2

Therefore: $\mathbf{F = m \times a = kg \frac{m}{s^2}}$

In vacuum environments, or when there is no air resistance, the motion of all bodies will accelerate in a uniform manner downward (a = constant); this acceleration is called gravity acceleration and is indicated with a "g".

Near the earth's surface we have: **g = 9.81 m/sec²**

The weight force F is the force that acts on a body in free-fall and is equal to:
F = m x g
In the SI system, the force F is expressed in N and the surface in m², and therefore the pressure p shall be:

$$p = \frac{F\ (force)}{A\ (surface)} \quad \frac{N}{m^2} = Pa\ (Pascal)$$

SI Measuring units, multiples and submultiples

	MULTIPLICATION FACTOR	PREFIX	SYMBOL
MULTIPLE	10^{12} = 1.000.000.000.000	Tera	T
	10^{9} = 1.000.000.000	Giga	G
	10^{6} = 1.000.000	Mega	M
	10^{3} = 1.000	Kilo	k
	10^{2} = 100	Hecto	h
	10^{1} = 10	Deca	da
	10^{0} = 1		
	10^{-1} = 0,1	Deci	d
	10^{-2} = 0,01	Centi	c
	10^{-3} = 0,001	Milli	m
	10^{-6} = 0,000 001	Micro	µ
	10^{-9} = 0,000 000 001	Nano	n
	10^{-12}= 0,000 000 000 001	Pico	p
	10^{-15}= 0,000 000 000 000 001	Femto	f
	10^{-18}= 0,000 000 000 000 000 001	Atto	a

The dimension scale referred to the most used measuring unit, the meter, is described below as an example:

Tm = Tetrameter= 10^{12} m
Gm = Gigameter = 10^{9} m
Mm = Megameter = 10^{6}m
km = Kilometer = 10^{3} m
hm = Hectometer = 10^{2} m
dam = Decameter = 10^{1} m

m = Meter

dm = Decimeter = 10^{-1} m
cm = Centimeter = 10^{-2} m
mm = Millimeter = 10^{-3} m
µm = Micrometer = 10^{-6} m
nm = Nanometer = 10^{-9}m
pm = Picometer = 10^{-12}m
fm = Femtometer = 10^{-15}m
am = Attometer = 10^{-18}m

Magnitudes may be measured in accordance with multiples and submultiples of the different units. The previous table illustrates their related names and symbols.

1.3 TEMPERATURE SCALES

Kelvin	Celsius	Fahrenheit
0 K	-273,15 °C	-549,67 °F
273,15 K	0 °C	32 °F

0 K = absolute zero
0 °C = 32 °F, melting point of ice at atmospheric pressure

- **Kelvin scale** called thermodynamic scale is used in physics;
- **Celsius scale,** is the most often used temperature scale and this temperature range is expressed in centigrade degrees;
- **Fahrenheit scale,** another temperature scale is used where the atmosphere's thermal condition is generally close to freezing point.

Using the Celsius scale has the inconvenience of applying the symbol + or – before the number that represents the temperature's degree.
Temperature conversion: **ratio**

$$°C = \frac{°F - 32}{1,8} \qquad °F = 1,8 \times °C + 32$$

$$°K = \frac{°F - 32}{1,8} + 273 \qquad K = °C + 273$$

Chapter 2

ATMOSPHERE – AIR

2.1 AIR COMPOSITION

The matter that surrounds us materializes in three defined forms such as:

- **Solid**: it has a defined shape and volume;
- **Liquid**: it has a defined volume, and it adopts the shape of the container that confines it;
- **Gaseous**: it has no shape and no volume, filling any available space entirely.

The molecules of solid bodies are provided with a great cohesive force that determines their shape.
Otherwise, the molecules of gases have repulsive forces that tend to separate them. Therefore, a gas may be only kept in a container by filling its volume entirely, independently from its shape and whatever the amount of gas is. Liquids and gases share fluidity, and for this reason they are defined as fluids.

2.2 AIR

A gaseous envelope surrounds the earth and is held closely by the force of gravity during its rotating and revolving movements.
This envelope is the atmosphere and the gases that compound it are the air.
Atmospheric air is a mixture of gases; its composition is almost constant up to an altitude of about 20 km.

The following elements are dissolved in air:

Element	Volume
Nitrogen	78 %
Oxygen	21 %
Rare gases and others	1 %

Small variations occur in the air's composition due to the presence of solid particles such as dust and crystals, or due to traces of other gases such as carbon monoxides, nitrogen oxides, ammonia, etc.
Moreover, atmospheric air contains water vapors that determine its humidity levels.

Chapter 3

ATMOSPHERIC PRESSURE

3.1 AIR WEIGHT

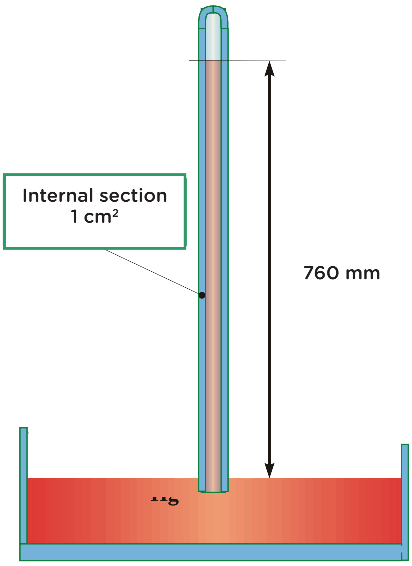
Solid bodies have their own weight, and gaseous bodies such as air also have their own weight.
If we weigh an empty cylinder, and then fill it with gas and proceed to weigh it again, we will notice a difference in its weight. The cylinder weighs more when it is full.
Furthermore, air, that is a mixture of gases, has its own weight and the load that its mass exercises on the earth's surface and on everything that is in its contact is huge.
In 1630, the physicist Evangelist Torricelli from Faenza demonstrated that the atmosphere (that is, the air surrounding the earth) weighs 1.033 kg on each cm^2 of surface measured at sea level (zero altitude).
This is the definition of ATMOSPHERIC PRESSURE.

Now we have to make a consideration: if the average man's skin surface is about 1.5 m^2(15000 cm^2) and, if the weight of the atmosphere equal to 1.033 kg presses on each cm^2 , 15500 kg would be the weight on the whole body's surface.
But the atmospheric pressure acts in every direction and, is also pressing on the body internally with the same value, it is therefore balanced.
In addition, the blood's circulation produces a pressure that is slightly higher than the one of the atmosphere in the internal walls of the vessels.
For these reasons, such a huge weight does not crush us.
One of the atmospheric pressure's features is its capability of changing according to the altitude at which it is measured.
Pressure decreases at higher altitudes than above sea level because the air stratum is thinner and it therefore weighs less.

ALTITUDE m	PRESSURE Mpa	TEMPERATURE °C
0	0,1013	15
100	0,1001	14,4
200	0,0989	13,7
500	0,0955	11,8
1000	0.0899	8,5
1400	0,0856	5,9
1800	0,0815	3,3
2000	0,0795	2
2400	0,0756	-0,6
3000	0,0701	-4,5

3.2 TORRICELLI'S EXPERIENCE

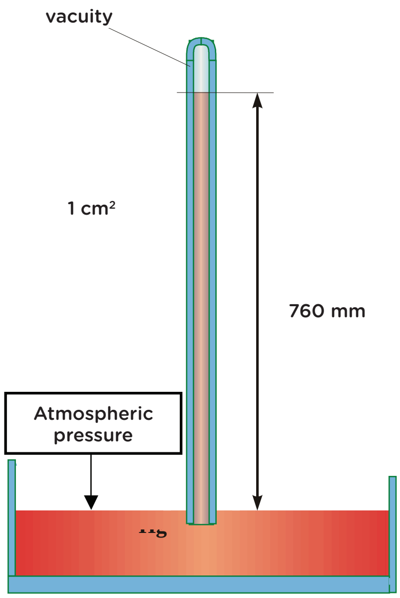
Take a transparent tube of about a meter long, closed at one end and open at the other one (figure 3.2), fill it entirely with mercury (Hg) and close the opened end with your finger. Turn it upside down and immerse it into a container with more mercury and we can see that, after having removed our finger from the open end, part of the mercury in the tube passes to the tub.
The mercury stops passing to the tub when the tube's level has reached a certain point.
In fact, measuring the difference between the tub's level of the mercury and the mercury in the tube we can notice that this difference is about 76 cm.
The reason why the mercury has not been emptied into the tub is due exclusively to the atmosphere's air weight.



As previously said, the air exercises a pressure equal to 1.033 kg on each cm^2, and therefore, this pressure shall also be exerted on the surface of the mercury contained in the tub.
The upper part of the tube, after having being turned upside down, is completely empty of mercury and air. A vacuum has been created, and the atmospheric pressure is totally lacking.
In this case, the atmospheric pressure inside the tube, instead of exercising its action from its top and from its bottom, acts only from the bottom toward the top.
As the experiment shows, this thrust on the surface unit is equal to the weight of the mercury column according to the tube's section.

Atmospheric thrust = 10,033 kg/cm^2

$$\text{Unit weight of the mercury column} = \frac{\text{Weight (kg)}}{\text{Section } (cm^2)} = 1{,}033\ kg/cm^2$$



In the Torricelli's tube, the mercury rises due to the atmospheric pressure

Proceeding with the same operations, employing water instead of mercury and using an 11 meter long tube, we can see that the water level inside the tube will reach 10.033 m from the surface of the tub.
This thrust, according to the tube's section, is equal to 1.033 kg on 1 cm^2 surface.

3.3 PRESSURE MEASURING DEVICES

we refer to pressures we must distinguish:

– **Atmospheric pressure**, a pressure caused by the air's weight (about 1 kg/cm^2);

– **Gauge or Relative pressure**, a pressure higher than the atmospheric pressure, that is measured by instruments called manometers (pressure gauges);

– **Absolute pressure**, the sum of the two previous pressures (gauge pressure + atmospheric pressure);

– **Depression**, a gauge pressure lower than the atmospheric pressure measured by instruments called vacuometers. Its maximum value is referred to barometric vacuum or absolute vacuum.

In the international system (SI), the atmospheric pressure at sea level is equal to

100.000 Pa
Which are equivalent to 0,1 Mpa

In the physics system, this pressure is equal to

101.325 Pa = 0,1013 MPa

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

4.2 VACUOMETERS OR VACUUM GAUGES

Vacuometers are manometers that measure pressures lower than the atmospheric pressure.
In industrial facilities, depression is measured with Bourdon instruments that may be graded in decibars, in cm of mercury or mm of water, according to the purpose for which they are to be designed.

Chapter 5

PHYSICS OF GASES

5.1 COHESIVE FORCES – REPULSIVE FORCES

The atmospheric air is a gaseous compound made up by molecules, such as solid bodies.
The molecule is the smallest combination of atoms that constitutes a chemical compound.
As has been already said:
In solids, the molecules are subjected to high intensity attracting forces that make them cohesive, forcing them to maintain in a specific position.
In liquids, this intensity is not so intense, and therefore the cohesive forces are weak.
Liquids in fact have their own volume and they adopt the shape of the container that encloses them.
In gases, as well as in air, no cohesion exists among the molecules, and they are free to move in such a way that their relative distances change continuously.
This force, called repulsive force, tends to separate them increasingly from the adjoining ones, being the reason why gases have no shape or their own proper volume, and tend to occupy all the available space.
In their movement, these molecules collide with themselves very fast, drift away from each other, and remain in constant contact with the container that encloses them.
Molecular collision releases a force on its wall, and the sum of all these collisions on the contact surface expresses the pressure.
The pressure appears with forces that act from inside to outside of the container.
The total volume of the gas molecules is very small when compared with the volume of the tank that contains them, so it is possible to decrease their reciprocal distances by means of compression, thickening many molecules into a specific volume, in such a way as to obtain higher pressure.

During this operation, we will notice a temperature increase within the tank.
The base physical laws that bind the parameters of the gaseous status, pressure, volume and temperature are two:

Boyle-Mariotte's law
Gay-Lussac's law

5.2 BOYLE-MARIOTTE'S LAW

At a constant temperature, the volume of a perfect gas enclosed in a container is inversely proportional to the absolute pressure, which means that for a specific amount of gas, the product of the volume by the absolute pressure is constant:

$$p_1 \times V_1 = p_2 \times V_2 = p_3 \times V_3 = \text{———————} = \text{constant}$$

5.3 GAY-LUSSAC'S LAW

The volume of an amount of gas at a constant pressure is directly proportional to the temperature:

$$V_1 : V_2 = T_1 : T_2$$

And consequently, at constant volumes, any pressure changes are directly proportional to the changes in temperature:

$$p_1 : p_2 = T_1 : T_2$$

From which we may notice that passing from an initial pressure to a higher final pressure there shall be an increase in temperature and inversely, passing to a lower pressure the temperature decreases.
Compression generates heat and expansion absorbs heat.

Boyle-Mariotte and Gay-Lussac's laws **are valid in an exact way only in the case of perfect gases**. Real pure gases such as hydrogen, oxygen, nitrogen or mixtures of gases such as air follow the laws mentioned above with a good approximation, especially when the pressures are moderate and the temperatures are not very low.
In pneumatics, temperature changes are very low, while changes in pressure and volume are remarkable. Therefore, Boyle-Mariotte's law is basic for measuring the greater part of pneumatic transmission components, from tanks to actuators
.

5.4 HUMIDITY OF THE AIR

A certain percentage of water vapor is always present in the atmospheric air.
When the atmospheric air turns cold, it reaches a point where the water vapor saturates. Any further decrease in the temperature implies that all the water may not remain in the form of vapor.
The quantity that may remain depends on the temperature.
The following table shows the maximum amount of water contained for each m^3 of air, expressed in grams within temperatures ranging from –40°C to +40°C.
An m^3 of compressed air is able to contain the same amount of water than an m^3 of air at atmospheric pressure. The data in this table is referred to the air in atmospheric conditions at the indicated temperatures.

Temperature °C	0	+5	+10	+15	+20	+25	+30	+35	+40
g/m3 atmospheric	4,98	6,86	9,51	13,04	17,69	23,76	31,64	41,83	54,11

Temperature °C	0	-5	-10	-15	-20	-25	-30	-35	-40
g/m3 atmospheric	4,98	3,42	2,37	1,61	1,08	0,7	0,45	0,29	0,18

5.4 HUMIDITY OF THE AIR

The relative humidity is the ratio between the content of water in the atmospheric air at a determined temperature and the content of water at the saturation point expressed as a percentage.

$$\text{U.R.} = \frac{\text{Content of water in the air}}{\text{Content at saturation}} \times 100$$

Example:
Temperature 20°C   U.R. 60%
How much water is contained in 1 m^3 of air?

$$17{,}69 \times 0{,}6 = 10{,}61 \text{ g/m}^3$$

When compressed, its capacity to contain water vapor depends exclusively on its volume, which shall be evidently reduced; therefore the water shall condense at constant temperatures.

Example:
5m^3 of atmospheric air at 20°C with U.R. 60% are compressed at 6 relative bars.
How much water will condense?

At 20°C, 5m^3 of air may contain no more than **10.61 g/m³ x 5m³ = 53.05 g**
The volume compressed at 6 relative bars shall be:

$$p1 \times V1 = p2 \times V2 \text{ as resoult } \frac{p1}{p2} V1 = V2$$

$$\frac{1{,}013 \text{ atmospheric bars.}}{6 + 1{,}013} \times 5 = 0{,}722 \text{ m}^3$$

0.722 m^3 of air at 20°C contain no more than **17.7 g/m3 x 0.722 m3 = 12.78 g**

The amount of condensed water shall be **53.05 g - 12.78 g = 40.27 g**

The condensed water shall be removed before being injected into the network.

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/cm^2
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/cm^2	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.

Chapter 7

FLOW RATE OF GASES

7.1 NORMAL LITER

In the SI system the flow rate of gases, and therefore of air, is expressed in:

m^3/s bzw. m^3/h (volumetric flow rate)
kg/s bzw. kg/min (massive flow rate)

Practically, in pneumatics, we refer to air at its free state and therefore, we employ the ***normal liter,*** identified symbolically as Nl.
It should be preferable to use the lower case letter in order not to confuse it with N (Newtons), yet the use of the upper case letter is common.
Employing the cubic meter as a volume measuring unit, we can speak of a normal cubic meter (nm3).
The normal liter is generally used as a measuring unit and the international system admits it the same as the bar due to its practicality.

7.2 FLOW RATE

The volume of fluid that passes across a section in a given time unit is defined as the volumetric flow rate Q.

$$Q = \frac{V}{t} \left[\frac{m^3}{s}\right]$$

The flow rate may be calculated by multiplying the speed of the fluid by the area A of the passed section.

$$Q = u \times A$$

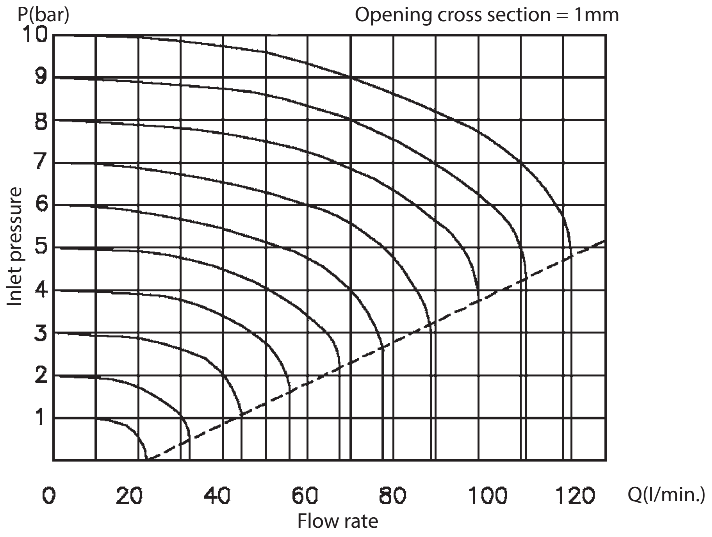
Being the speed u expressed in m/s and the area in m², we shall have:

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

In the SI, the measuring unit of the flow rate is m³/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 mm² 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.

If a device has a section equal to 5 mm², it shall be sufficient to multiply the resulting value by five in order to know the flow rate of this section.

5 x 55 = 275 l/min

Appealing to the calculating formula referred to the capacities for subsonic streams:

$$Q = 22{,}2 \times S \times \sqrt{(P_2 + 1{,}013) \times (P_1 - P_2)}$$

$$Q = 22{,}2 \times 5 \times \sqrt{(5 + 1{,}013) \times (6 - 5)} = 272{,}187 \text{ l/min}$$

The value obtained is very similar to the one detected using the diagram.

Chapter 8

PNEUMATICS

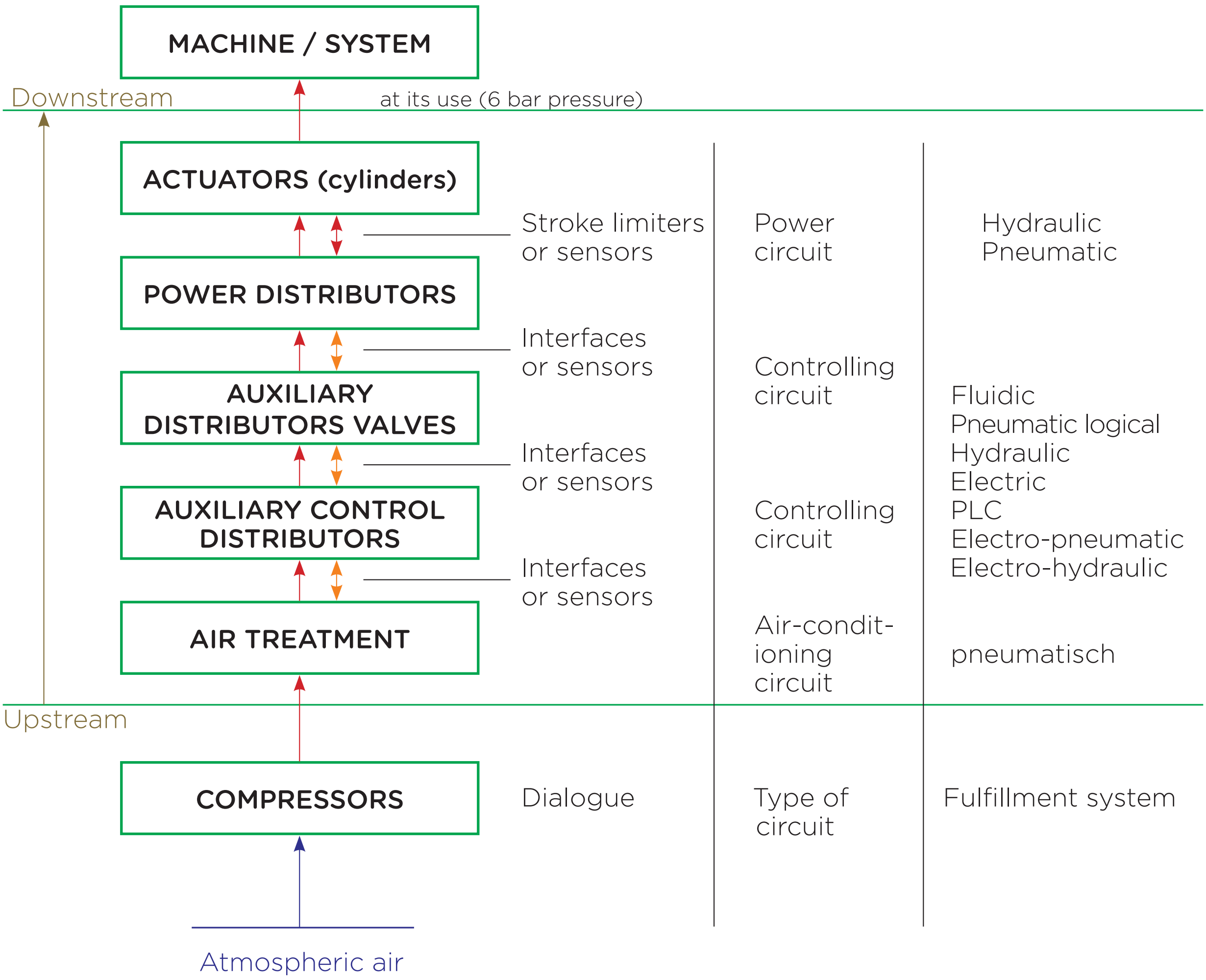
8.1 PNEUMATIC AUTOMATION

Pneumatic technology is no longer represented only by a cylinder and its respective control valve, but is something quite more complex.
Interfacing with other technologies, such as electronics, allows pneumatic automation to obtain results that were unthinkable a few years ago.
In fact, pneumatic automation is able to satisfy a great part of the emerging needs and, in certain cases, is irreplaceable.
Pneumatics is easily employed wherever an automated movement is needed.
Its limited costs and high reliability, that determine lower producing costs and best quality, are a few other reasons for its increasing employment.
The productive sectors involved are uncountable, and only to mention a few examples, we can find pneumatics acting in sectors such as assembling machines, wood working machines, food and textile machines, packaging machines etc.
Compressed air must not be considered as a low expense to produce. Actually, compressed air is an expensive operation, but the advantages counterweigh its production costs.

8.2 PNEUMATIC AUTOMATION CIRCUIT STRUCTURES

If we consider the structure of any modern automatic equipment it shall be easy to observe how many different elements and components coexist: electric, mechanic, pneumatic and hydraulic.
Within this context, pneumatics finds its role and its reason for development, because each of the different technologies offers advantages that make it more suitable for some applications than others.
This explains why, even when each of the aforementioned technologies may be able to carry out by itself an entire installation, practically, the greatest part of these systems are hybrid in order to make best advantage of the features offered by each of these elements.

The diagram displayed below describes the circuit structure of a pneumatic automation system, from the source of compressed air to the operating connections of the different components and their respective dialogues with their interfacing elements. In this structure diagram we notice the entire sequence made by the fluid in order to start-up and activate a system, a machine or an automatic device.



Chapter 9

PRODUCING COMPRESSED AIR

9.0 PRODUCING COMPRESSED AIR

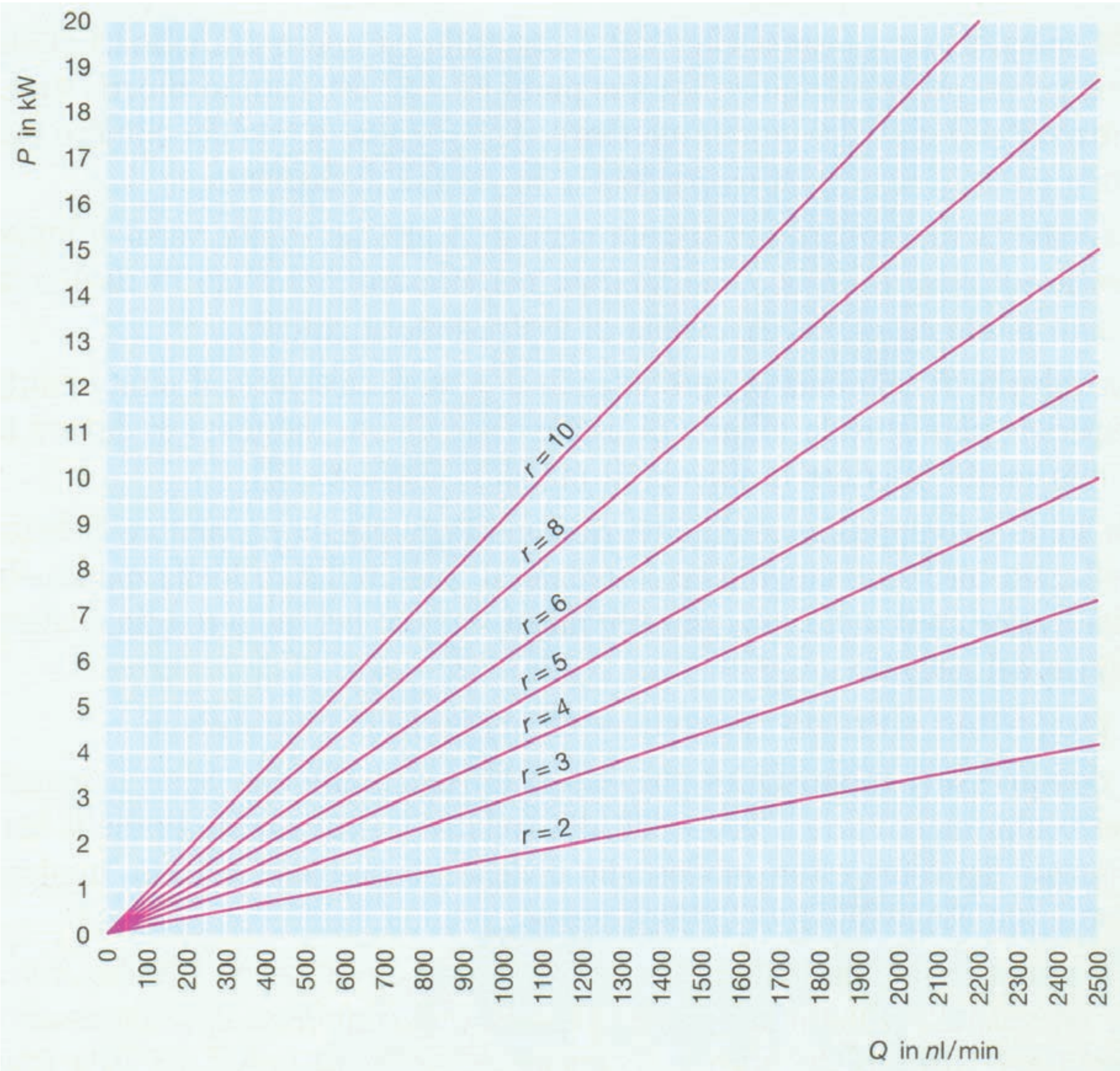
Today, compressed air is an essential element for the greater part of any industry.
The machines that produce air are known as compressors that, activated by engines, capture the atmospheric air and, once it has been compressed, transfer it to the users.
Those operators who deal with automation systems are not generally considered to be competent in the sector involved with compressing air or its production, but a basic knowledge must be part of any specialist's experience and is useful to understand the compressed air automation method.
Before entering into the different kinds of compressors, let us look at their pneumatic features and their magnitudes.

Suction pressure	**Pa**	
Discharge pressure	**Pe**	
Suction flow rate	**Q**	**(nm^3/s)**
Discharge flow rate	**Ql**	**(m^3/s)**
Compression ratio	**r = Pe/Pa**	**(Pascal)**

As has already been said, the term normal (n) expresses the volume of air under normal conditions, which means atmospheric conditions with the temperature at 20°C, and therefore nm^3 and nl.
The power needed to compress a volume of air at the discharge pressure is obtained by means of the following formula:

$$N = Q \times Pa \times 3{,}5 \times (r^{2{,}85} - 1)$$

An increase in the compression ratio decreases the performance η that must not to be lower than 0.7 with a compression ratio r lower than 5.
The following graph allows a quick choice of the power applied to the compressor, in accordance with the volumetric flow rate during suction.



9.1 COMPRESSORS

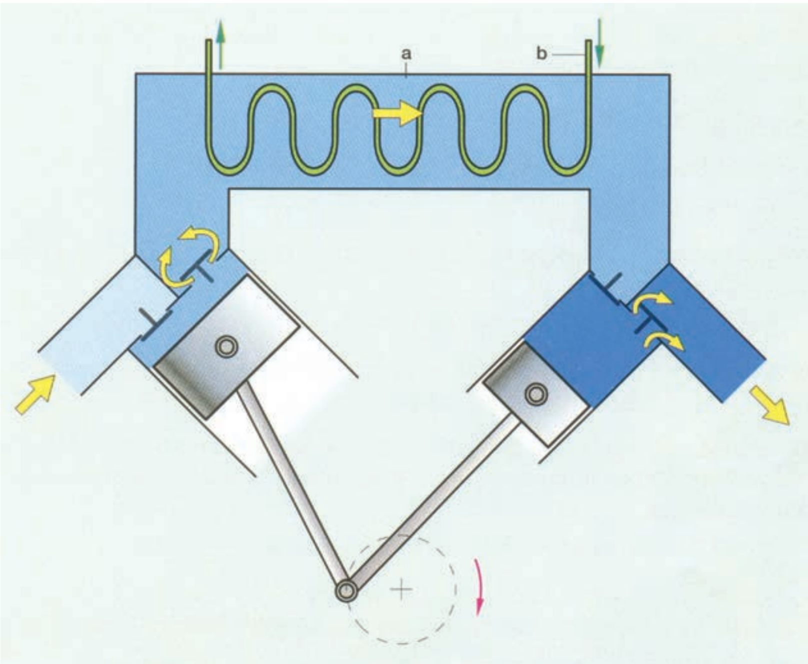
Compressors are divided into volumetric and dynamic.
Volumetric compressors are employed in pneumatic transmissions, which are divided into reciprocating and rotary.

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.



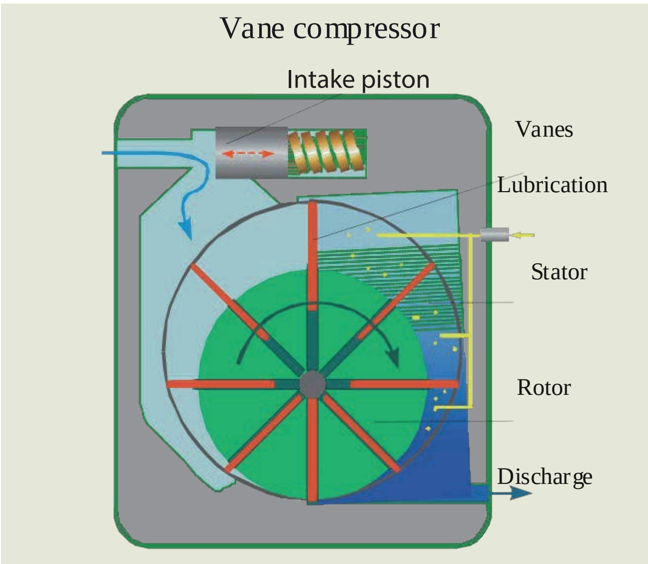
Up to	**1 bar**	**mono-stage**
Up to	**15 bar**	**two-stages**
Over	**15 bar**	**three or more stages**

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.

The system may be refrigerated either with air or with refrigerating liquid.
Reciprocating compressors need to be connected to a tank since their operation is intermittent.
When the set-up maximum pressure has been reached within the tank, an electric contact activated by a pressure switch blocks the motor's feeding and thus stops the compressor.
When the pressure decreases to a second set-up value (minimum value), a pressure switch will activate the motor's electric circuit, thus restarting the compressor.

Rotary vane compressors

These kinds of compressors include a cylindrical envelope (stator) where a drum (rotor) rolls eccentrically and this body is contains radial grooves. In these grooves, thin steel plates flow rate and during rotation they move toward the stator as a result of the centrifugal force. By means of slits made on the stator, the air is suctioned by the vanes to a higher volumetric condition, and is progressively compressed during the rotor's rotation.
At the point of maximum volume reduction, the compressed air is carried to a second opening located on the stator and sent forward to be used.
These compressors are defined as continuous duty compressors, meaning that they keep working even when there is no downstream air demand.
In this situation, the suction valve, which is controlled by a spring checked piston, is closed and the compressor keeps on operating idle.
The rotary vane compressor also has the possibility of working without the downstream storage tank, thanks to the automatic suction regulating system.

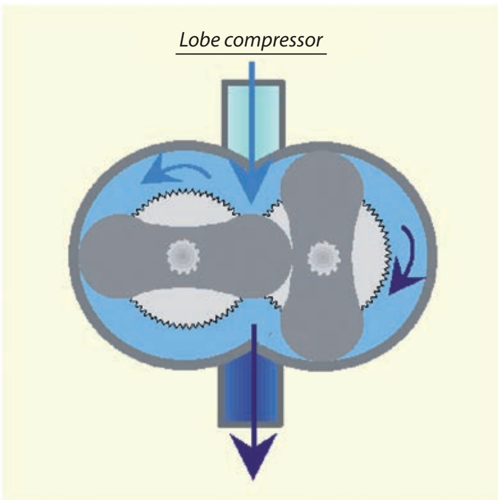


Rotary screw helical compressor

Screw compressors show performance features that are similar to the previous ones, but these stand out due to their quietness, thanks to the low number of bodies in contact during rotation.
They include two screw rotors with parallel axis, with their respective clockwise and anticlockwise propellers that roll opposite to each other.
Abundant lubrication is necessary in order to avoid air leaks and ensure rotor refrigeration.
The suctioned air is compressed owing to the particular shape of the screws that reduce the volume progressively, transporting it from one end to the other, or rather, from the suction port to the end user port.
As the vane compressor, it may work idle, being equipped with the same suction control device.
Rotary compressors are able to supply excellent capacities with pressures close to 10 bars.

Lobe compressors

These compressors are not often used due to their modest performance. In fact, they generate pressures up to a maximum of 3 bars with poor capacities.
Two gears are assembled rigidly on each of the two lobes and are free to roll. In their rotation they suck up the air and carry it from the inlet to the discharge.
The coupling between the two lobes is very precise, and does not allow leaks between inlet and outlet. Compression is not carried out in the chamber but at its discharge, and this explains its poor capacity to supply relatively high pressures.



9.3 TANKS

The tank has the function of storing the compressed air and returning it to the users whenever they may need it.

The compressor is to be chosen according to the flow rate method, and the tank must be able to supply sufficient air to the system during the compressor's idle phase.
Storage of air inside the tank also allows removing impurities that are mixed in the incoming air by the compressor, depositing them at the bottom.
These impurities, such as condensation, dust, oil, etc., shall be released at regular intervals by means of an automatic discharge valve placed at the bottom of the tank.

Sizes

Compressor tanks may be calculated simply, with a reliable approximation, using the following formula:

$$C = Q / 60$$

Where C = capacity in m^3 of the tank Q = flow rate in m^3/hour

If a piston compressor has a flow rate equal to 50 m^3/hour, it shall need a downstream tank with a capacity equal to 0.83 m^3 (830 liters).
We shall choose a standard 1000 liter tank.

Rotary compressors equipped with suction regulation should not need the downstream tank, but the following formula may be used whenever necessary:

$$C = Q / 600$$

For a vane compressor with the same flow rate as the previous one, the tank shall need 0.083 m^3 (83 liters).
We will choose a standard 100 liter tank.

It is worth noting that tanks with a capacity greater than 25 liters are subjected to testing by the bodies mentioned above to ensure safety.

9.4 REFRIGERATORS AND DRYERS

During compression the air's temperature increases to such values that it acquires an absorption rate higher than the value of the water vapor contained at the moment of its suction from the atmosphere. It is absolutely necessary to eradicate the possibility that water contained in the air may be sent through the distribution ducts.
If warm air enters directly into the distribution network, and subsequently cools during its travel through the pipes, the dew point decreases and the water vapor condenses in the pipes, this water will flow with the air and result in water supplied to the equipment.

Multistage compressors are equipped with inter-stage refrigerators with their respective water separators, but the dehumidification is not complete since the compressed air at the final stage still has a high temperature.
The greater part of the water must be removed before the air enters into the distribution network.
This removal is obtained by chilling the air with specific devices called final coolers, that are installed between the compressors and the tanks.

These coolers may be:
Water circulation, air circulation or refrigerating cycle coolers.
The latter are equipped with a coil containing cooling liquid that favors the dew point, bringing the air's temperature that circulates in the refrigerator down to about + 3°C. Because the temperature decrease, the condensed water settles in a container and is discharged by a water separator, equipped with an automatic discharge valve.
Dryers produce more loaded dehumidification, using substances that exploit the capacity of capturing the vapor contained in the air.

Dryers may be:
Absorption or adsorption dryers.
Absorption dryers exploit the hygroscopic principle (capacity to absorb humidity) of certain materials such as caustic soda. The hygroscopic components will have to be substituted regularly because they absorb the water in the air and become saturated.
Adsorption dryers exploit the principle of adhesion (capacity of keeping the water on its own surface) of materials such as silica gels.
They are regenerated regularly with air that blows the adsorbing element.

Chapter 10

COMPRESSED AIR DISTRIBUTION

10.1 PIPING

In industrial applications, pipes must be sized properly for electric and water systems. The type of system may change according to its use and applications, but in each case it must satisfy needs such as:

- Minimize pressure drops between the compressor and the end users
- Reduce air leaks in joints and keep leaks to a minimum
- Ensure that water is removed by employing water separators.

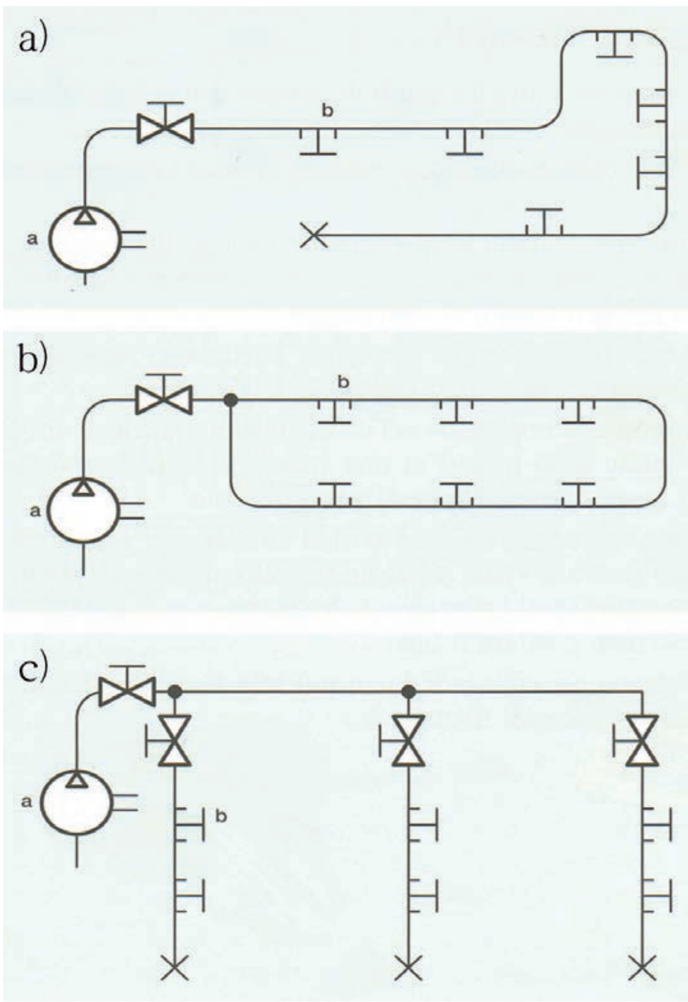
The compressed air is distributed to the point of use by means of a series of main piping systems that represent the system's arteries.

Sizing of this piping must be performed in such a way that, even in the farthest point of the network, flow rates and pressure are maintained within acceptable ranges, and any pressure drops resulting from head losses are to be kept within values around 0.3 bars.

10.2 DISTRIBUTION NETWORKS

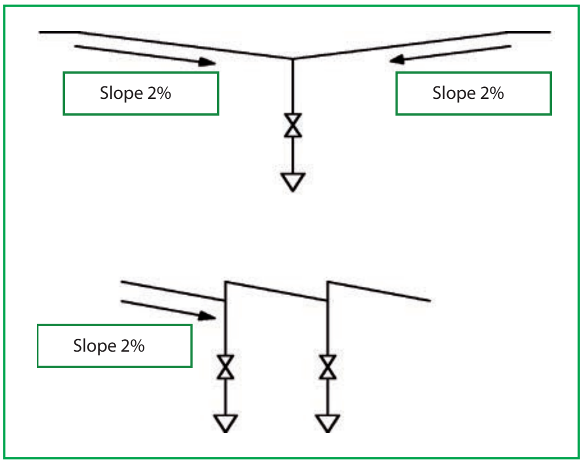
Building a compressed air distribution system depends on many factors such as: size and structure of the environment, number of draw off points, their disposition, etc.

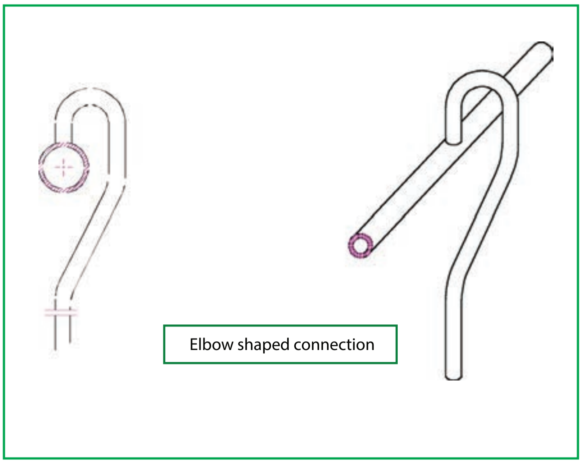
Except for new installations, more often than not, the network is the result of further extensions, and is therefore branched. Its size is usually not supported by specific calculations, but is carried out based on the needs existing at the moment of its extension.
The best method is to design the main piping with a closed loop in mind, in order to connect it with other parallel piping to the main pipeline, in order to obtain a mesh overhanging the surface to be serviced. With other small derivations, air may be available at every point.
This system has the advantage of offering the air at several parallel ways where to flow with a remarkable reduction of head losses.
The piping must be installed in such a way that it will not obstruct the movement of hoists or any other suspended loads, and must be painted blue, in accordance to the regulations that the colour blue identifies compressed air ducts.



a) Open loop
b) Closed loop with mesh prearrangement
c) Branched

The piping's layout must be planned at a 1 to 2 % inclination in the direction of the air flow, and must include water collecting wells (also called water traps) at the end of each course of the duct, with the possibility of draining downward and must be easy to discharge the moisture.
The pipes that deliver air to the users of the air must be detached from the main duct at the upper wall, by means of elbow connections (based on the shape of the connection), in order to prevent water from reaching the users.
The recommendations mentioned regarding branched, open loop or closed loop networks are described in the following figures.

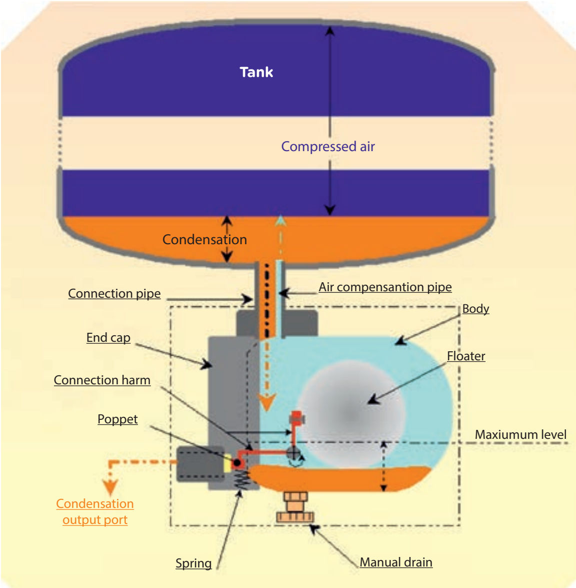




Shut-off valves are installed at the most suitable points of the network, which are useful to section off different areas for any eventual maintenance and/or extension activities, without the need to deactivate the entire system.

10.3 WATER SEPARATORS

Once the water has been separated from the compressed air, and once it settles in the pipes, it is collected in traps equipped with a device called a water separator.



Condensation automatic drain

Automatic discharge is always advisable in these units, because they are frequently located in very inaccessible places, and a simple manual discharge tap would not be very practical.

10.4 HEAD LOSSES AND SIZING

A difference of pressure is necessary to maintain an air flow through a piping system, in order to overcome friction resistance due to tube wall roughness and the connections. The degree of pressure drop depends on the tube's diameter and length, its shape, the roughness of its walls and on the speed of the fluid that passes through it. A pressure drop is an energy loss, and therefore increase operating costs.
An installation is accurate when the head losses that occurs in the piping, from the compressor's tank up to the users, is about 10000 – 30000 Pa (0.1 – 0.3 bars) and it is usually advisable that it should not be higher than 5% of the operating pressure. The speed of air in the piping must not be greater than 10 m/s. Introducing the piping's length we must consider its connections and fittings. For ease of calculation, any head losses determined in these elements are equalized for a tube whose length presents the same head losses.
The section of the main duct depends on:

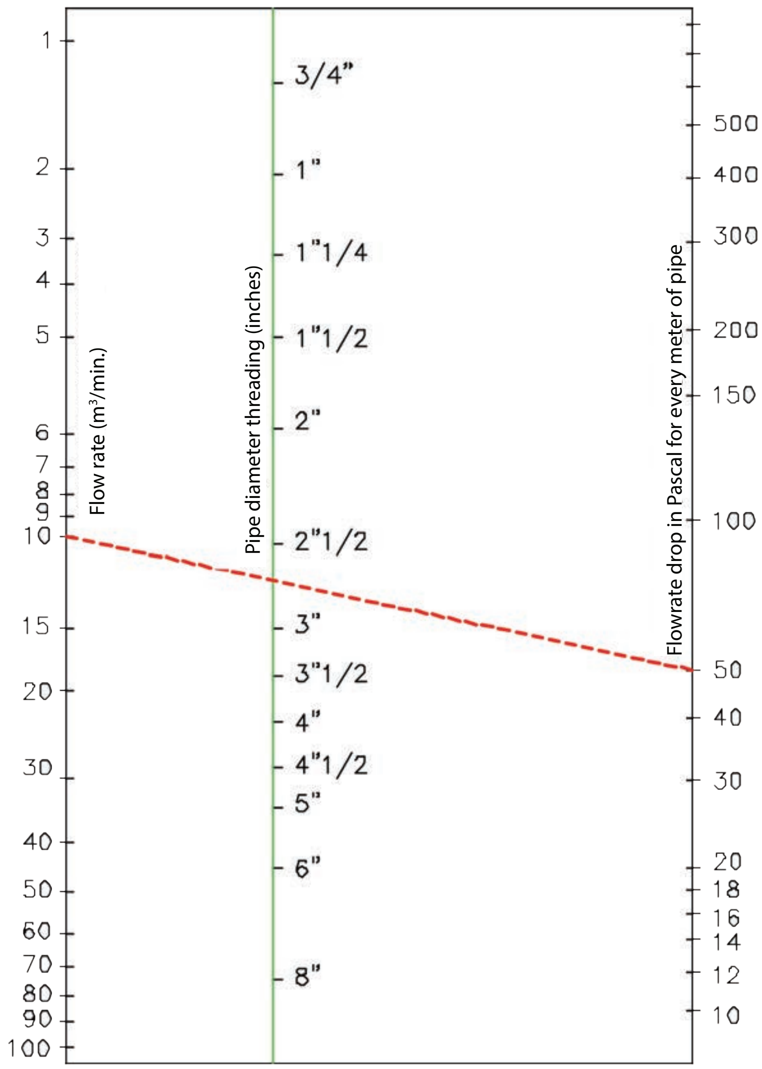
- Pressure rates
- Difference of pressure between compressor and the last end user point

- Maximum sudden flow rate, counted with the maximum number of working end users
- Total main duct length
- Connections, shut-off valves, curves etc. that determine pressure drops.

Suppose having a distribution network that must supply 10nm³/min and imposing a 0.1 bar pressure drop for an equivalent tube length equal to 200m, with a respective operating pressure equal to 7 bars.
Therefore, for each meter of piping we will have a pressure drop equal to 50 Pa.

10000 Pa / 200m = 50 Pa/m

In the chart, join the required 10 nm3/min flow rate value to the vertical right axis 50 Pa (head losses). The matching point located at the central vertical axis determines the internal diameter of the tube.



Cart to determine air duct tube diameters for a gauge pressure equal to 7 bars

Considering the piping's length, we must ponder that head losses due to connections, shut-off valves, etc., as has been said, are equalized to the length of a tube that presents the same loss features, and they shall be counted along the entire line.
The following table shows head losses in branch tubes and in the most common valves with equivalent length.

Valves, etc.	Equivalent length in m of tube						
	Internal diameter of the tube in inches						
	1	1 ,5	2	3 1/4	4	5	6
Membrane valves	1,2	2,0	3,0	4,5	6	8	10
Gate valves	0.3	0,5	0,7	1,0	1,5	2,0	2,5
Elbow connections	1,5	2,5	3,5	5	7	10	15
T connections	2	3	4	7	10	15	20
Reductions	0,5	0,7	1	2	2,5	3	3,5

Chapter 11

COMPRESSED AIR TREATMENT AND USE

COMPRESSED AIR TREATMENT

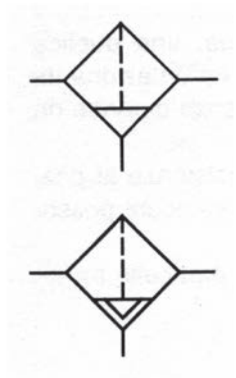
Once the compressed air is distributed, it needs further treatment in order to be adequate to the pneumatic equipment it will supply with air. This means to remove any foreign particles suspended in the air with suitable filtration and to reduce and stabilize the pressure, which in networks is variable, at a lower and constant value than the one existing in the distribution system. Whenever necessary, lubricant mist and micro-mist oil shall be supplied to the moving parts of the devices.
The structure of an air treatment device is:
- Filter
- Pressure regulator and manometer
- Lubricator (whenever necessary)

11.1 FILTERS

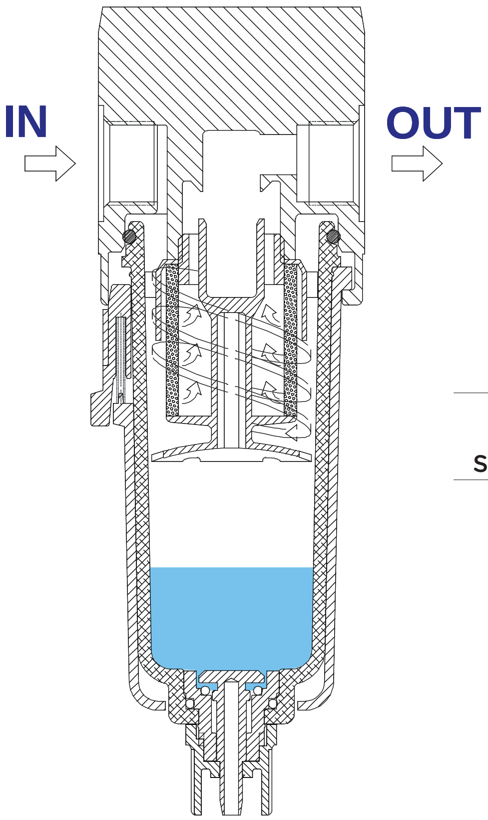
Filters remove solid particles as well as the humidity condensed from the compressed air.

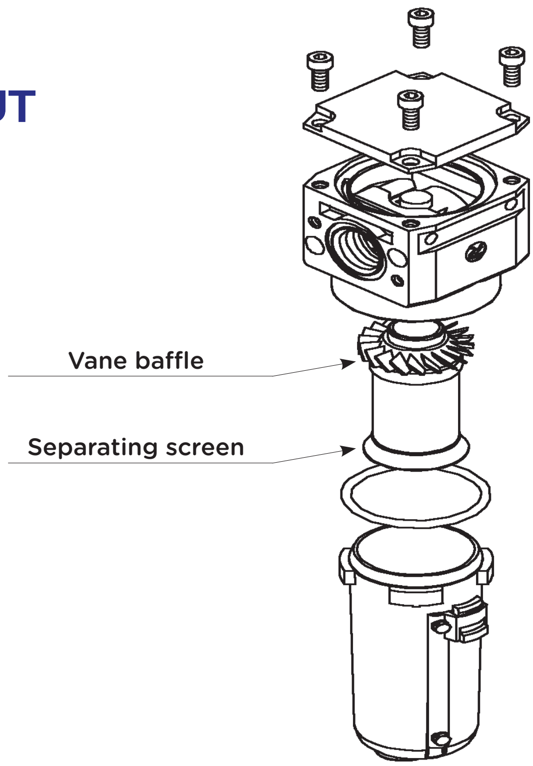
It is known that air does not contain only water vapor, but also solid particles and degraded oil vapors produced by the compressor, etc.
The task of any filter, at the user's point, is to clean the air completely from the moment it is placed in-line, after the suction and line filters have carried out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

Manual drain

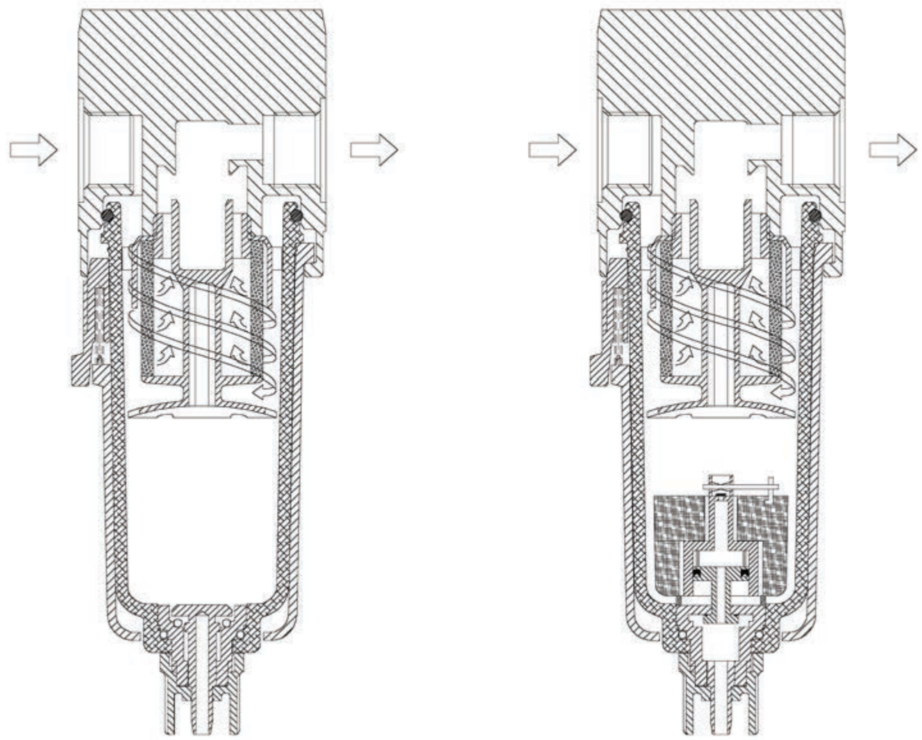


Automatic drain



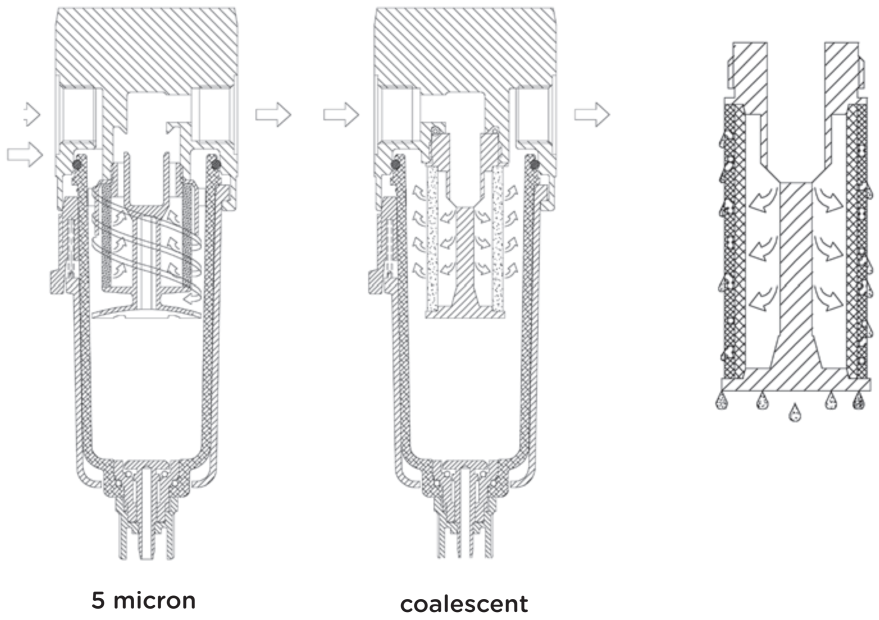


Referring to the figure, the air enters through the top of the device (IN) and finds a fixed baffle with inclined vanes that force it to rotate rather violently. Water drops and large solid impurities are projected against the glass wall by the centrifugal force and fall to its bottom due to gravity.
The glass's content is protected from the turbulent upper area by a separator which behaves as a screen, keeping the lower part stagnant. This allows the water to remain at the bottom without being sucked into the network.
Before leaving the device the air is forced to pass through a filter cartridge in order to remove the smallest impurities, and then it flows toward the outlet (OUT). Cartridges, or filter elements, are classified based on their porosity, which determines the smallest impurity particles that they are able to retain. For example, a 50 micron filter retains all the particles that have a rated diameter equal to or larger than 50 microns.
Cartridges for greater filtrations are also designed: 5 and 20 microns.
The cup is manufactured with transparent high-resistance materials such as polycarbonate or nylon and is protected by shockproof techno-polymer casings. Certain metal protections have been designed for greater sizes or for particular applications.
A water discharging device is placed at the lower part of the cup, which may be a simple manual tap or an automatic float tap.

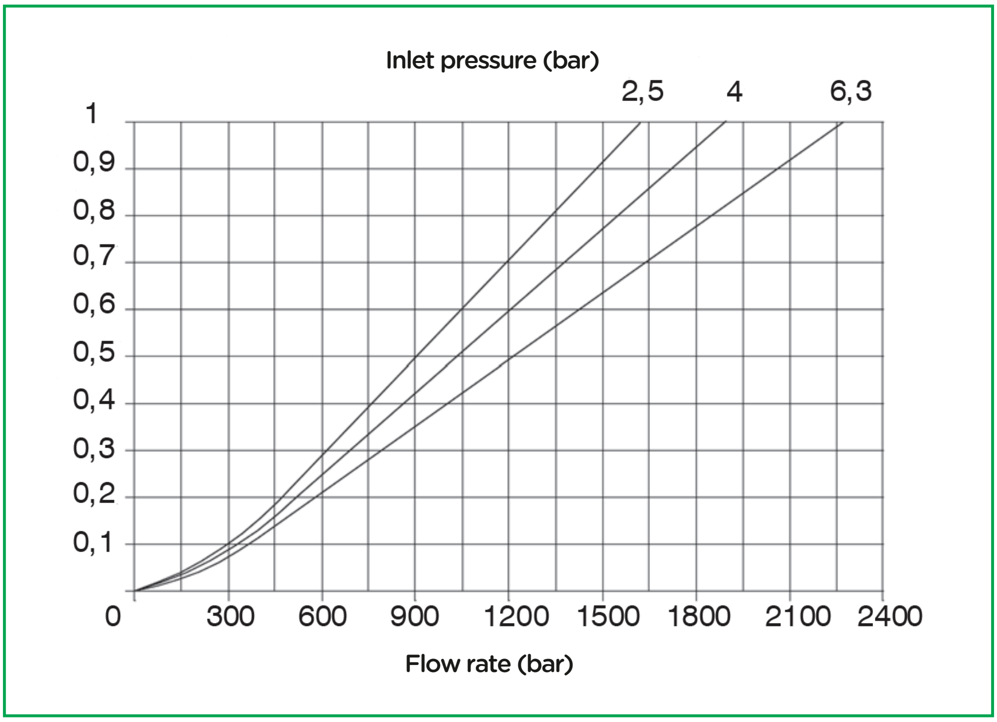


Manual discharge **Automatic discharge**

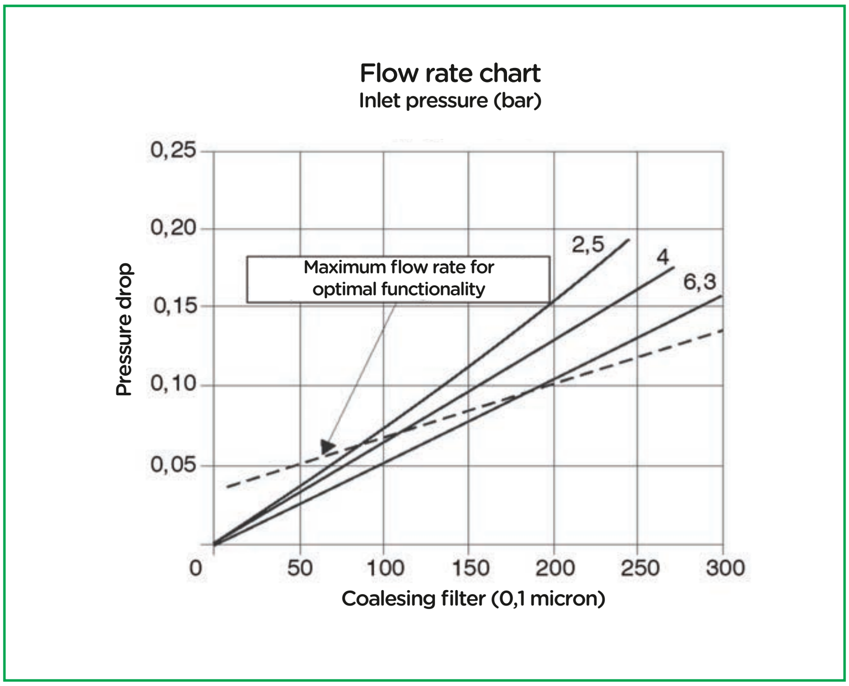
For applications where better filtration is needed, we can use a filter that is able to remove oil particles and residual micro condensation from the air, favoring agglomeration of the liquid particles in order to produce drops that fall to the bottom of the glass. The cartridge's porosity, made with enveloped fibers, is equal to 0.1 micron and allows having 99.97% air technically free of oil. These filters employ the coalescence physical principle, which is why they are called coalescent micro-filters.
But it is necessary that these filters be preceded by a pre-filter with a 5 micron filtration value in order to avoid early contamination of the coalescent cartridge.



The pre-filter retains solid impurities with a rated diameter equal to 5 or more microns, and the other filter, in addition to retain remaining solid impurities up to 0.1 microns, transforms the suspended water and oil particles into liquids, carrying them to the bottom of the glass.
It is useful to remember that all filters need regular maintenance by removing and substituting any dirty cartridges and emptying the liquids stored in the cup when the discharge is manual.
A full cartridge produces higher head loss levels than normal under equal flow rate conditions.
Their sizing is performed considering the required capacities and pressure drops accepted between their inlet and outlet.
In order to function smoothly, the filter must have a pressure drop of at least 0.1 bars.
In their technical datasheets, the manufacturers point out data regarding flow rates and drops under different operating pressures, obtainable from diagrams that assist correct choice of the device.



Filter standard (5 – 50 micron)

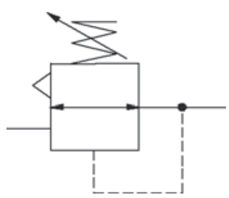


Coalescent filter (0.1 micron)

These diagrams are helpful in order to choose the right filter.
If the flow rate requirements may call for a 900 Nl/min standard filter with an operating pressure of about 6 bars, rising from the axis of the flow rate up to the respective 6.3 bar curve, we can detect a pressure drop equal to 0.35 bars at the respective vertical axis. This means that during absorption of the mentioned flow rate, the pressure of the filter downstream has decreased to about 5.9 bars.
Moreover, the diagram shows that if the air requirements should increase considerably, the drop also increases and should turn intolerable when its value is about 1 bar. In these cases it is necessary to choose a greater sized device.
For coalescent filters with equal size, the flow rate is lower due to cartridge porosity and it is therefore advisable to follow the indications described in the respective diagram for optimal operation.
All flow rate and drop values included in the area below the dotted line are to be considered correct.

11.2 PRESSURE REGULATORS

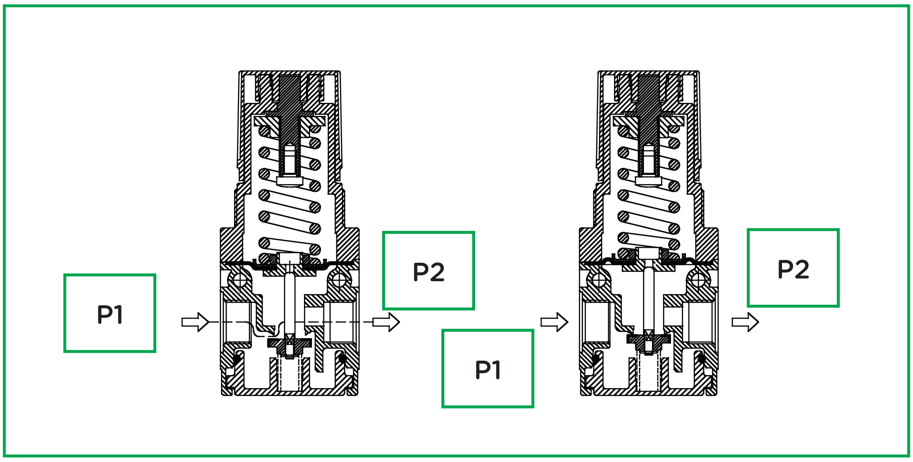
A pressure redugulator is a device that allows reducing and stabilizing the air pressure available in the system.
It works according to the proportionality principle of supplying a pressure at its outlet that is proportional to a reference signal.
Its employment is always necessary to supply the correct downstream pressure in order for the equipment to function properly.
In most cases the reference signal is constituted by the force produced by charging a spring with a regulation screw.
As high is the produced force, as high shall be the pressure returned at the outlet.



Operation

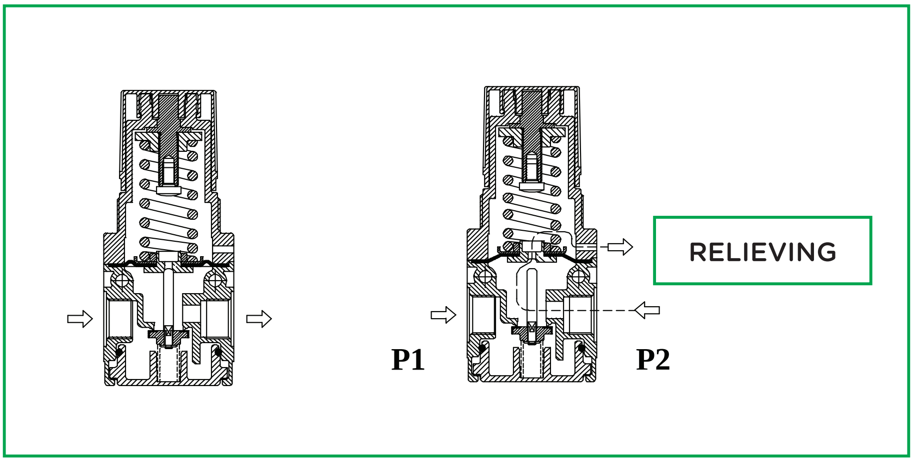
In order to set up a secondary pressure that shall be mandatorily lower than the operating pressure, we must act on a screw that loads the regulating spring, which, acting on a membrane, pushes a shaft integrated to a shutter.

This action allows opening an air passage from the entrance toward the outlet. We shall call the first pressure P1 and the second pressure P2.
P2, that feeds the equipment downstream, rises and starts to react on the lower surface of the membrane contrasting the force of the spring that acts on the upper part.



Once a balance between the two forces has been reached, the shutter valve returns to the closed position. When consumption is required, P2 decreases together with the opposing force on the lower part of the membrane. The shutter moves downward opening a passage that allows compensating the consumption.
The shutter remains closed without any air consumption.

Relieving Function

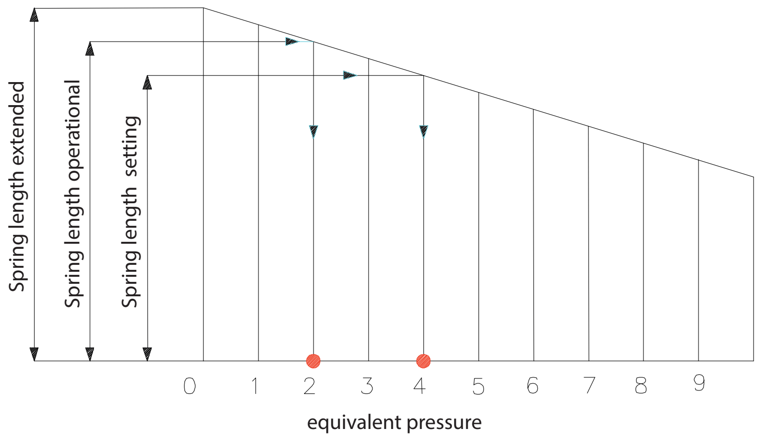


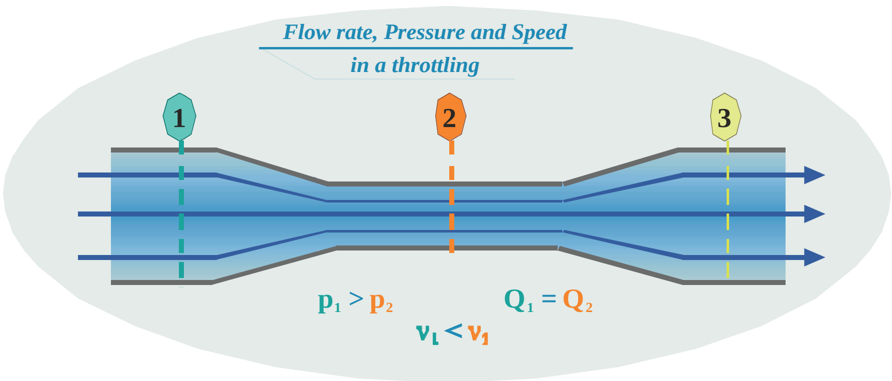
If for any reason pressure P2 should increase more than the set-up value, the membrane rises moving away from the shutter's shaft.
A small hole made at the center of the membrane is opened discharging the excess to the atmosphere through a hole made on the bell.
This function is known as relieving.

Flow Rate Compensation

With high air consumptions the shutter is opened significantly and the spring that acts on the membrane is extended according to the run performed by the shutter.
The force exercised by the spring is weaker than the one with the closed shutter (set-up value).
The balance between the two forces (spring/pressure P2) is produced at a lower value. Observing the diagram, we can see that the pressure equivalent to the force produced by the spring stands at a much lower value than the calibrating one.
It would be necessary to increase the flow rate to a higher value than the one of consumption. In order to do that, it is necessary to use the Venturi tube's physical principle.

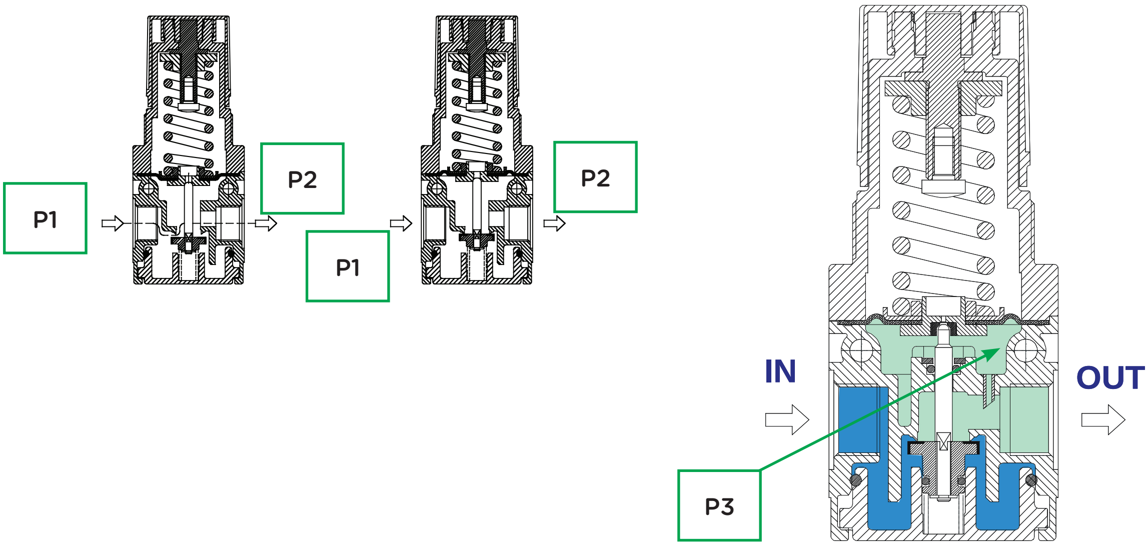
Diagram of the spring and its equivalent pressures





It is useful to remember that the Venturi principle is based on the decrease of the section in a tube crossed by both liquid and gaseous fluids.einem flüssigen oder gas-förmigen Medium durchströmt wird.

The figure described in the previous page schematizes the constriction condition of a section of this tube and the passage of fluids from sector 1 to sector 2. The fluid's speed increases immediately after this constriction and pressure P2 decreases with respect to P1, keeping the flow rate unchanged. The pressure increases again when the section returns to its initial value, sector 3.



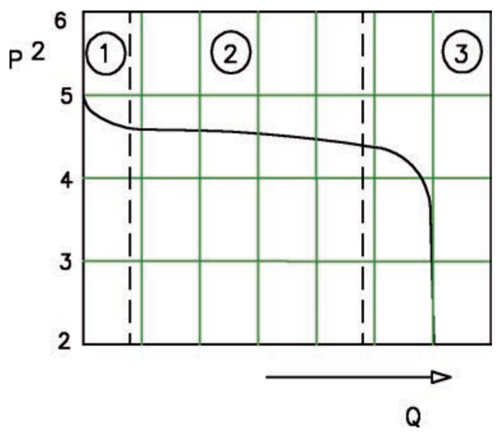
As we can see, the chamber of P2 is no longer in direct contact with the lower part of the membrane. In fact, a third chamber, P3, has been created that is connected to P2 by means of a small hole placed in the constriction point toward the outlet, recreating the Venturi tube's situation.
In a similar instance, the part below the membrane "feels" a lower pressure than the real outlet pressure (P2) forcing the spring to open more and consequently the shutter does so as well.
This allows to increase the flow rate and supply more air than the one consumed. A tube, with an angled end and directed toward the outlet, placed at the center of the flow rate near the constriction, enhances the Venturi effects, balancing the flow rate properly.

Pressure compensation (shutter balancing)

The inlet pressure P1 is subjected to fluctuations existing in the distribution network that affect the regulated pressure P2. In fact, we notice certain pressure increases in P2 when P1 decreases, as well as certain decreases in P2 when P1 increases. Different values for surfaces that are exposed to the pressure on the two shutter faces cause this phenomenon. These opposite forces must be equalized in order to cancel each other, so that inlet pressure fluctuations do not influence the regulated outlet pressure.

Reducer size

The reducer must be sized in order to satisfy the required flow rate with an acceptable set-up pressure drop. The device's flow rate capacity depends on its size and the data is described in the diagrams that pneumatic equipment manufacturers include in their own technical datasheets.



The curve represented in the diagram is divided into three sectors:

1) Initial condition, with the shutter open and with a small opening that does not allow any adjustments, since the air flow rate demand is very low. Any response in case of changes to air flow rate demand is impossible.

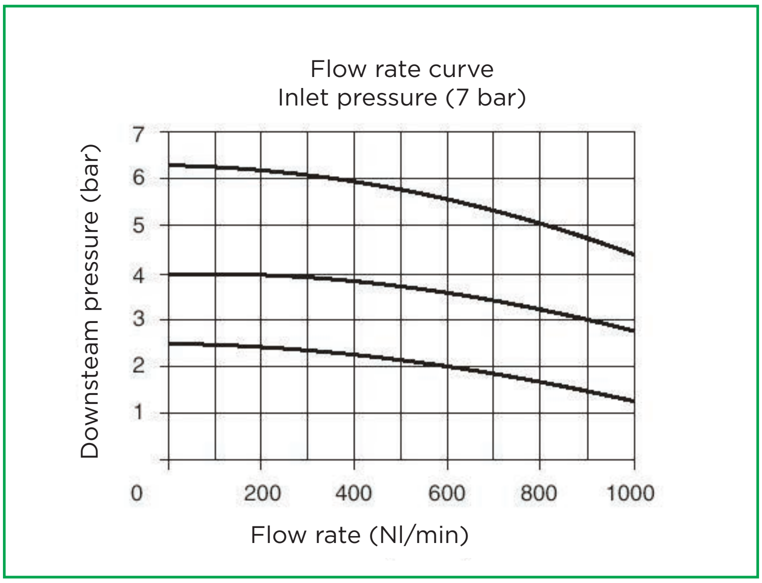
2) Usable regulation range

3) Critical condition where the shutter is completely opened with maximum air flow rate demand. The air reaches its maximum allowed speed and pressure P2 decreases sharply.

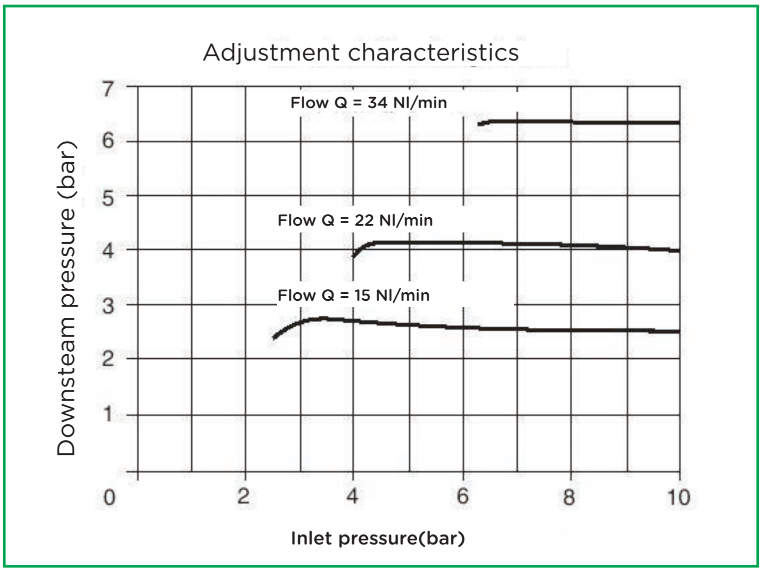
The area marked with number 2 is the one described in reducer choice diagrams. Areas 1 and 3 are cut because they represent unsuitable conditions for proper device operation.
A large regulation range requires a spring with reacting features stronger than those expected for a lesser range, since available space for the spring housing is fixed.
If, for example, we would set up a pressure equal to 1.5 bars at outlet P2, we should use a spring calibrated and regulated from 0 to 4 bars and not one with a maximum regulation from 0 to 12 bars.
Even if apparently a more rigid spring should satisfy the expected regulating conditions, we must consider that compressing it slightly it should produce a sufficient force on the front part of the membrane in order to impose the planned 1.5 bars outlet pressure.
The shutter should open a small opening and the operating situation illustrated in the diagram should be produced at sector 1, which is not a correct condition, as already said.

Otherwise, a spring calibrated from 0 to 4 bars needs a greater compression ratio to produce the same reaction and, allowing a larger shutter run, it works in correct operating conditions in area 2 of the diagram. It is easy to guess that if we want to work with a regulated pressure near 4 bars using the same spring, we should move to area 3 of the diagram and any further flow rate demand shall not be met.

Characteristic curves



Flow rate curves and their respective drops in P2 under different operating pressures

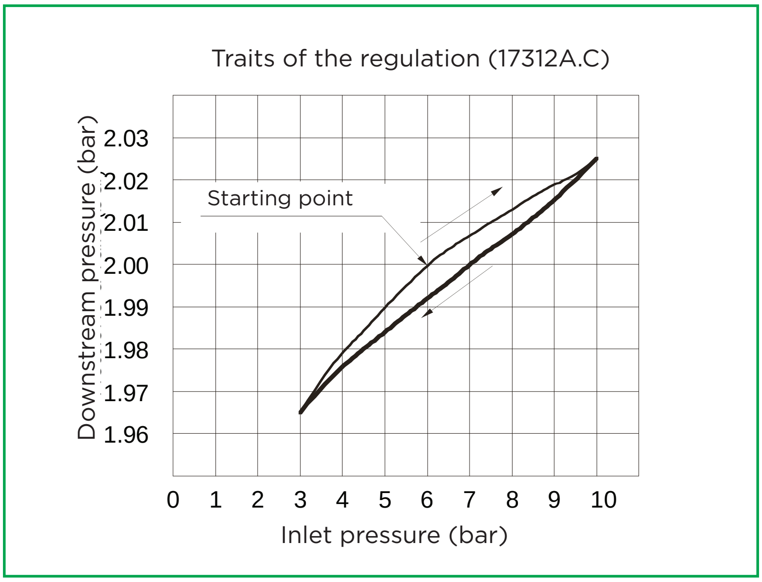


Variation of the downstream pressure P2 based on pressure P1 variations

The first diagram refers to the choice of the regulator based on the necessary flow rate.
If the requested consumption should be equal to 400 Nl/min, and if we should regulate the outlet pressure to 6.3 bars with P1= 7 bars, during the absorption of this flow rate we will have a pressure drop in P2 of about 0.3 bars. Increasing the flow rate, the drop also increases naturally.
The second diagram shows the influence of the operating pressure on the set-up pressure P2. A fixed consumption is forced at different regulated pressures in order to verify that variations to the set-up value at different P1 pressures shall be produced.
The ideal characteristic should be a line parallel to the axis of the upstream pressures, because it would mean a perfect balance of the initial curve where the operating pressure and the regulated pressure have the same value.

Hysteresis

Hysteresis is the phenomenon that influences the performance of both P1 and P2.
In a mechanical transmission system hysteresis is caused by the friction of moving bodies.



In a pneumatic system hysteresis is produced by frictions of gaskets, as well as the unilateral deformation of frontally sealed gaskets when they are compressed on the gasket's seat, as well as to mechanic resistances caused by membrane deformations. To this purpose, they are not flat but wavy in order to reduce this resistance to a maximum. Hysteresis comes from the Greek "histerein" that means be back or to come too late. If we consider a 10 wagon train as an example, when marching forward, the locomotive, representing the dominant value, has a certain distance with respect to the last wagon. Marching backward, this distance decreases.
It is due to the fact that the wagon coupling has a certain movement and that backward they touch their buffers.

This is useful to explain the two different values of P2 at the same P1 if it is considered to be an upward rather than downward P1 set-up value.
P2 always follows the variation of P1, that is the dominant variable, with a small delay. As steeper are the curves, higher is the influence of P1 on P2, as well as larger is the space between the two curves, and stronger is the hysteresis effect.

Repeatability

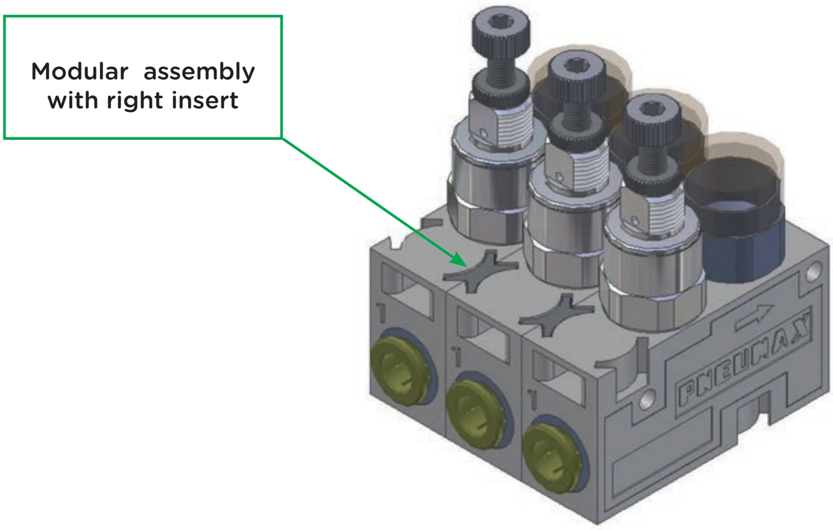
This term defines the deviation from the set-up value of P2 when the operating pressure P1 is removed and then restored.
It is expressed as a percentage of the P2 set-up value.

Other regulators

Sometimes we could use particular regulators that include a manometer (pressure gauge) in the regulating knob that marks the secondary pressure.

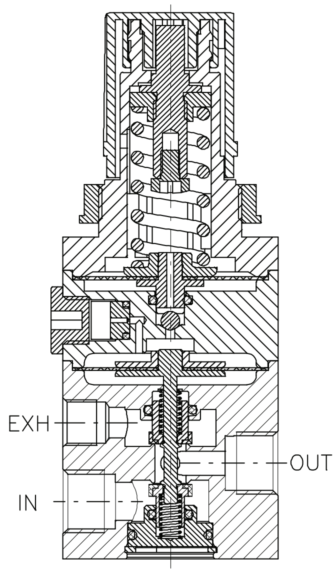
This avoids drilling the machine’s control panel savings time and money. The diameter of the manometer is obviously reduced in order to allow its direct housing. This kind of solution is not advisable when it is necessary to read the pressure on the dial from considerable distances.
Whenever it is necessary to power a set of regulators with the same line, we can use equipment designed for this purpose, and that may be assembled easily and quickly in modules on the common supply line.
The outlet, which in standard regulators is opposite and in line with the feeder, is located on the side normally used for the manometer at 90° with respect of the feed supply.

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

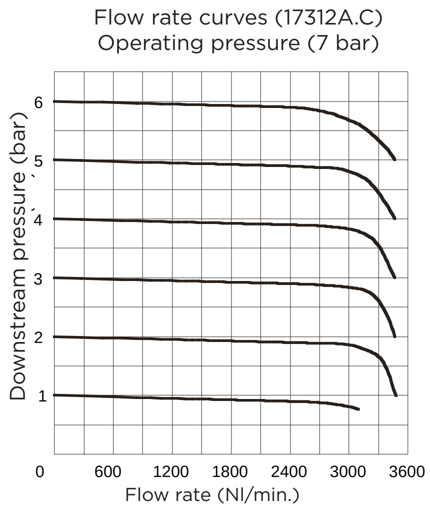


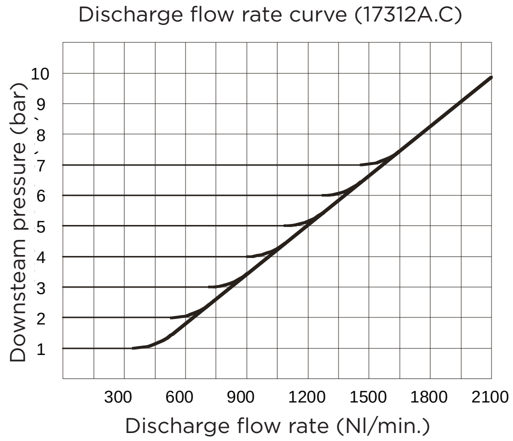
Precision regulators

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.



This creates a pressure in the chamber below that acts on the upper part of the second membrane that pushes the shutter downward. The air is free to flow from the inlet IN toward the outlet OUT powering the downstream circuit. The lower part of the second membrane "feels" the outlet pressure value and, finally, the generated reacting force shall counterbalance the force produced on the upper part of the membrane, thus closing the shutter. Any air request from the user shall overbalance the system and the shutter shall open immediately in order to meet the request.
For what concerns its power and discharge, prompt response is a basic feature for this kind of devices. In opposition to the standard regulator, the precision regulator's discharger has a remarkable flow rate, allowing proper restoration of set-up values even in downstream overpressure cases.

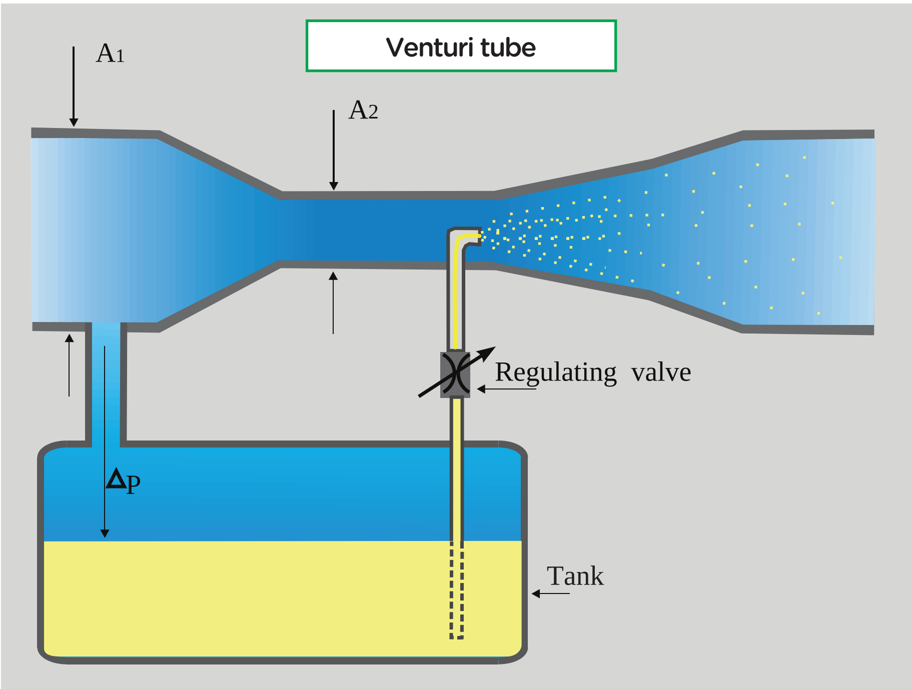




As we can see from the example shown in the first diagram, the downstream pressure remains constant and with significant absorptions of air before decreasing quickly when it reaches the critical flow rate. In fact, the run of the flow rate curves is almost parallel to the horizontal axis. For what concerns the discharge diagram, we can notice the substantial flow rate in different downstream set-up pressure situations.

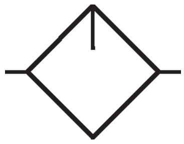
11.3 LUBRICATORS

Lubricators have the function of sending lubricating oil to pneumatic system's whenever needed.
Currently, lubricators tend to be used less frequent because some devices employed are suitable to operate without any further lubricating oil. The need for lubricators is sustained in particular applications, such as high-frequency performances or for actuators with long running and high actuating speeds.
Once a system is supplied with lubricants it will need to be lubricated always, even if the equipment is declared to be in conditions to operate without new lubricant supply. In fact, the oil tends to wash away the greases used for moving parts during their assembly, and therefore, if no lubrication is supplied, after certain movements dry operating condition would take place.
Lubricators use the Venturi principle to operate, and therefore they need to be crossed by an air flow to begin the phenomenon.

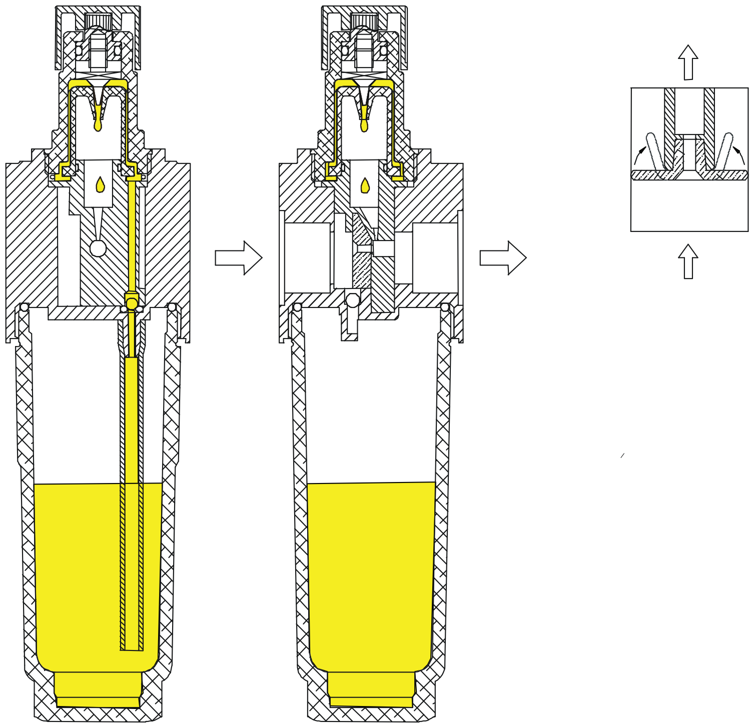


The design shows lubricators performance schematically, and how the oil mist is transported suspended along the compressed air ducts.
It produces a difference of pressure between sections A1 and A2 of the tube. In section A2 the pressure decreases and the flow speed increases. This difference in pressure causes the oil in the tank to be sucked rising along the small tube.
A flow control valve measures the oil introduced into the area where the air moves faster. The air breaks the drops and the smaller parts are dragged with it in suspension. The air and oil mixture may cover relatively large distances (up to 10 or 12 meters) but this depends on the system's structure.

This distance may be drastically reduced if the air flow should happen to pass through elbow, T and other similar connections. We must consider that the greater part of the lubricating oil shall be sent to those circuit areas where greater flow rate absorption exists.

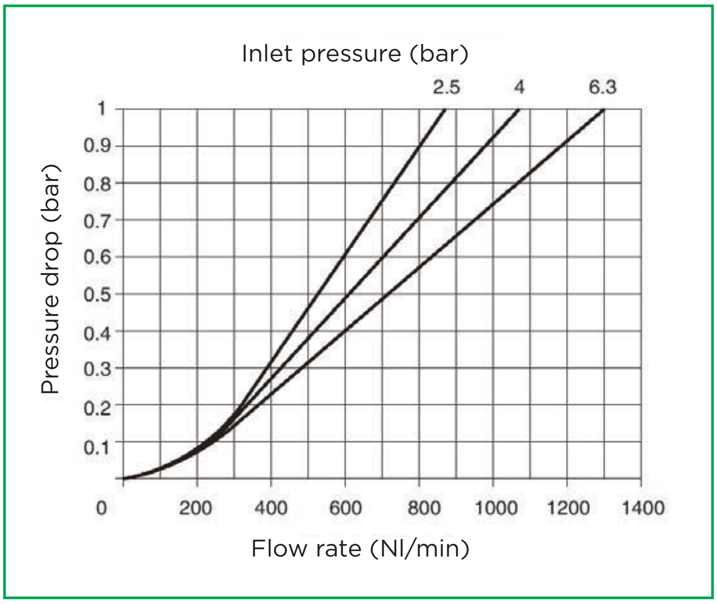


Always use oil that is compatible with the mixtures for the gaskets used in the equipment to be lubricated. Non compatible oil generates irreversible damages, causing volume swellings or reductions in the gaskets with which it enters into contact. Jamming or excessive air leaks are the most commonly produced damages.
Therefore, no lubrication may be better than using oil that is not suitable.
Being easily pulverized by compressed air oil is not enough, but it must also possess other qualities needed for best lubrication such as purity and stability against oxidation.
Oils for motor vehicle cannot be used due to their additives that restrain viscosity changes over a large range of temperatures, or that avoid production of foams, etc.
A viscosity that ranges between 23 and 32 cSt (centiStokes) allows effective pulverization and produces a sound film.
The oil flows along the piping's internal walls but it may find obstacles such as elbow, T and other similar connections that prevent the farthest points from being lubricated. For this reason, a system operating with lubricants must be designed carefully.
The used oil is expelled by means of discharging valves and when sent to the environment. It could be harmful to the environment if its concentration is higher than 5 mg/m3. It is advisable to use cleaners for the discharged oil that assist with separation of the oil from the air, and then collecting it in a cup.



The inside view of the lubricator highlights the cup containing the oil with its respective suction hose, and the transparent drip in the upper part that enables seeing the oil flow, with its own regulating valve. Instead, lateral magnification shows the Venturi valve (the arrows mark flow direction) with the central hole that represents the restriction. Some flexible lateral vanes allow the passage of higher flow rates than the Venturi valve's capacity.
In fact, the air climbs over the constriction, folding the vanes and ensuring the necessary flow rate. The oil supply is regulated by the user, who shall dose the number of drops needed for proper lubrication by means of the regulating knob.
About 10 oil drops per each m^3 of consumed air are enough to feed the system to be lubricated. A check valve along the suction hose prevents the oil from returning to the cup when no air demand exists. The amount of oil in the volume units remains constant even if the flow rate changes. Reliable calculations or systems for establishing the right amount of oil to be sent to the system do not exist. Very often, we find the right amount of oil due to experience gained over time. Oil flow should be kept constant over time. Regular checks must be carried out in order to control that the lubricator cup contains lubricating oil, and if this is not possible, the lubricating system shall be equipped with an indicator marking low cup oil levels.
It is absolutely not recommended to use lubricators in devices that may have small calibrated orifices or holes, such as precision regulators, proportional valves etc., because the oil could obstruct the air passage thus hindering their operation. Lubricators are used less frequently thanks to enormous progress in lubricating greases that offer high adhesive capacities. This allows them to remain longer at the lubricating point, for which they are defined as being long-term greases.
With these greases and suitable gaskets, all lubricating devices may operate without being supplied with any further lubricating oil.

Curve characteristics



Choice of the lubricators is determined by the flow rate value needed to power the system and by the respective head losses.
The diagram shows that different head losses exist at equal flow rates under three different operating pressures.

11.4 4 F.R.L. GROUPS

Conditioning groups constitute an essential unit that ensures a dry and clean air supply to the pneumatic components, with regulated pressure and lubrication whenever necessary.

They include a filter, a pressure regulator and a lubricator system interconnected in a single block. They are called F.R.L. indiction the initials of the single components, and they are mounted upstream of the equipment in the mentioned order.

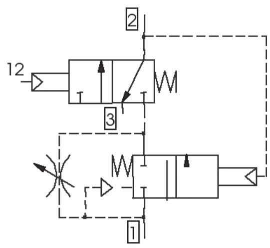
11.5 CHOOSING THE F.R.L. GROUP

The diagrams of use drafted by the companies of this sector must be analyzed in order to choose a group, taking into account all the necessary requirements for their proper operation.
These requirements involve required filtering degrees, necessary air flow rates, reduced pressure and any eventual lubrication needs.
A proper sized group shall be chosen based on these principles.
In many cases, a block with supplementary exits is interposed between the regulator and the lubricator system in order to allow air withdrawal free of lubricants.
Other devices may be added to complete the chosen group that, even if they are not applied to treat compressed air, perform other tasks and make the composed group functional to this purpose.
These devices are:

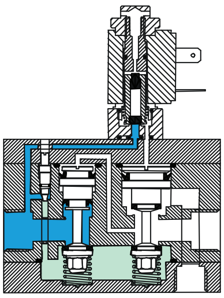
11.6 GRADUAL STARTER (PROGRESSIVE START)

When a circuit is fed with compressed air after being discharged completely (E.g. a machine starting up in the morning) the pressure supplied by the pressure regulators fills the entire system and the actuators with completely chambers empty (atmospheric pressure).
Unwanted movements of the machine's parts should be produced even with no manageable speeds. All this could damage the machine, besides being dangerous.
The air must be introduced into the circuit gradually in order to avoid malfunctions, making all the points of the circuit to be reached by the same pressure simultaneously.

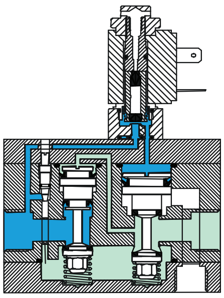
pneumatic activation



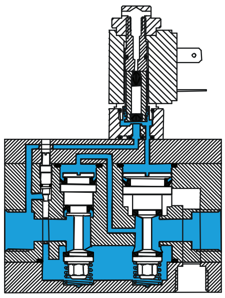
Any eventual irregular positions assumed by the actuators due to the absence of pressure in the circuit are to be restored “gently”, in order to avoid violent displacements that may cause damages.
Their activation may be carried out sending an electric or pneumatic signal to the device.
The gradual starter includes two valves properly connected to each other that allow sending compressed air to a circuit with gradual intake up to a pre-established pressure level and then full pressure may be released quickly.
Usually, this device is the last element of the conditioning group.



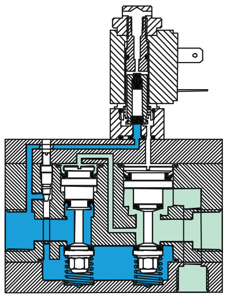
at rest



active with gradual release



active with full release

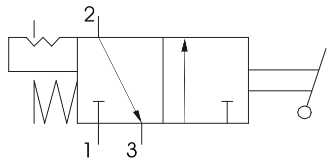


deactivated in discharging phase downstream

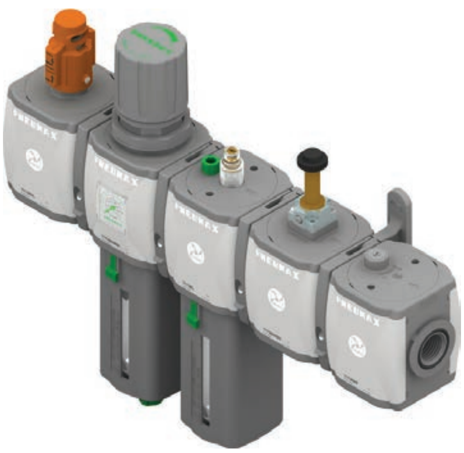
Referring to the symbols, we can easily understand how it works.
When control 12 is activated, the air passes from the feeding point 1 to the entrance of the upper valve by means of a flow regulator, and then is free to flow toward outlet 2. The flow regulator manages the gradual process. The outlet port 2 is also connected to the lower valve’s control attachment point. When the latter reaches its switching pressure level it opens the passage toward its outlet, which was closed until that moment, and that now feeds the upper valve directly, overriding the variable throttle. Therefore, full pressure is sent toward the circuit. The group is then completed by inserting a shut-off and dump valve before the filter, which enables disconnecting the entire system, including the conditioning group, from the distribution line.

11.6 SHUT-OFF VALVE

This valve may be equipped with an opening on the activating knob that allows inserting a padlock. Only the person in charge of maintenance who keeps the keys shall be able to restart the system, and carry out the maintenance procedures, so nobody may pressurize the system during this operation.



The following figure shows a complete modular group assembly. The simplified symbol represents only the filter + regulator + lubricator.

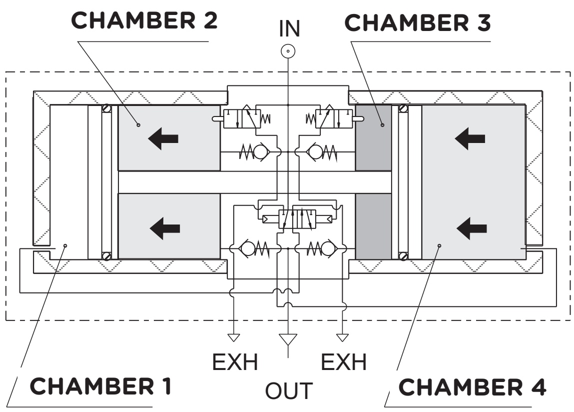


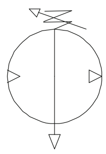
11.7 FILTER REGULATOR

The filter regulator is a device that integrates a filter and a pressure regulator in the same body.
The combined unit maintains the technical features of each device.
As we see in the figure, the filter is located in the lower part with the same performance of its respective size, the air being carried to the upper part where the regulator is located, that sends the regulated pressure toward the outlet. This unit allows cost savings and a reduction of space.

11.8 PRESSURE BOOSTER

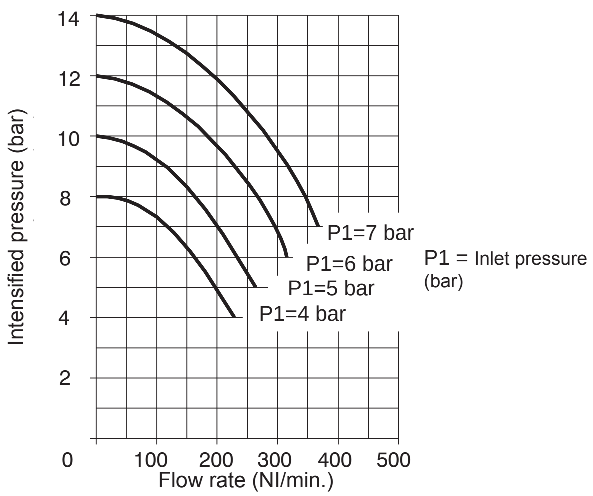
The filter regulator is a device that integrates a filter and a pressure regulator in the same body.
The combined unit maintains the technical features of each device.
As we see in the figure, the filter is located in the lower part with the same performance of its respective size, the air being carried to the upper part where the regulator is located, that sends the regulated pressure toward the outlet. This unit allows cost savings and a reduction of space.



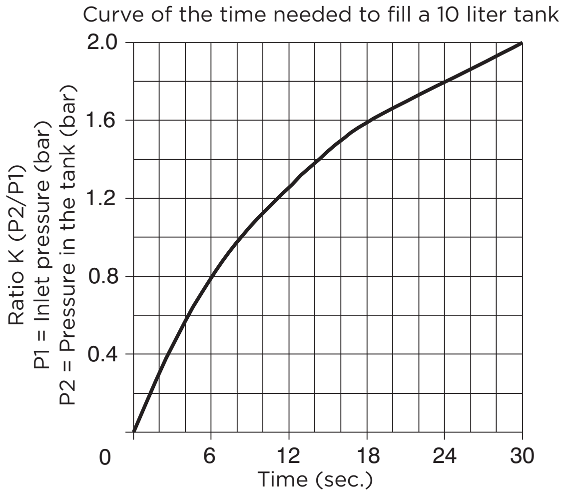


The operating principle is based on the pumping effect of a four-chamber cylinder, where two chambers alternatively push and compress the air present in the multiplying chamber, and the last chamber is set up for discharge.
A fluctuating circuit in the intensifier's central part, controlled by the end-of-travel sensors, allows sending air alternatively to the two sides of the device by means of a distributing valve.
Four check valves connected properly between each other allow sending air toward the outlet preventing its return.
The system shall fluctuate continuously until the force generated in the two thrust chambers by the respective pistons counterbalances the force generated in the compression chamber by its own piston.
This means that the pressure generated by the force acting on each piston shall be double with respect to the pressure that generates the same force acting on two pistons. Therefore, we shall have a double pressure at the outlet with respect to the inlet pressure.
Sometimes it may occur that a higher pressure in a single point of the system than the one used in the remaining part must be necessarily available, and the booster may solve the problem without need of sizing the entire circuit, including the compressor, for the higher used pressure.
But we must consider that this equipment must be used only to intensify the pressure and, having knowledge of the interested user's consumption, a tank with a proper accumulation volume must be included. This tank shall proceed to supply high air pressure whenever the interested user may demand.

This procedure is necessary, because in the face of air absorptions, the booster will keep fluctuating pursuing the consumption without ever reaching the desired pressure value.



As we can see in the diagram, if for example we follow the curve referred to 4 bars in feeding, the double value of the outlet pressure is only kept with zero flow rates. Introducing the consumptions, the outlet pressure decreases, and with absorptions equal to 300 Nl/min the multiplication factor becomes one. The booster keeps pumping without obtaining any results.
Therefore, it is necessary to proceed, as has been already said, considering that the device also needs a certain time to load certain volumes at the desired pressure values.



We can calculate the time needed to fill a given volume in order to pass from the initial pressure to the final pressure by means of the booster (ratio equal to 2).

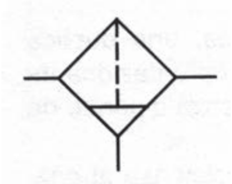
P1 = inlet pressure of the booster
P2’ = initial pressure in the tank
P2”= final pressure in the tank
V = volume of the tank

First, calculate the ratio K’ between the initial pressure in the tank and the inlet pressure of the booster (P2’/P1).
And then calculate the ratio K” between the final pressure in the tank and the inlet pressure of the booster (P2”/P1).
Identify the intersection point K in the graph, referring the value of K’, with the curve and go down to read the respective time T’.
Repeat the operation this time using the value of K” and read the respective time T”.
Now apply the following formula:

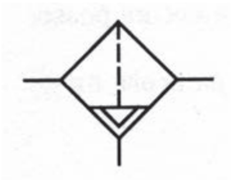
$$T = \frac{V}{10} (T'' - T')$$

We thus obtain the total time needed to take the volume V from pressure P2’ to the final pressure P2”.

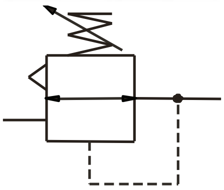
SUMMARY OF SYMBOLS



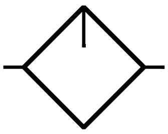
Filter with manual discharger



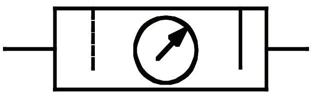
Filter with automatic discharger



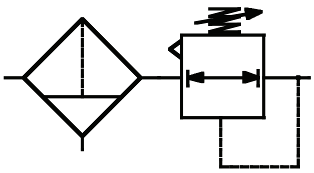
Pressure regulator



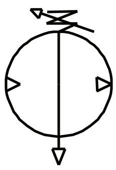
Lubricator



WF.R.L. simplified symbol



Integrated Filter regulator



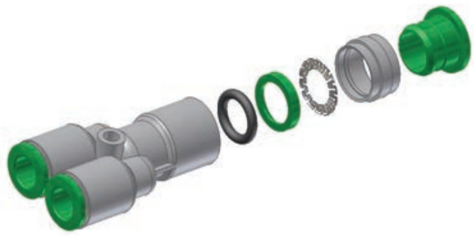
Pressure booster

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.



The most commonly used fittings are known as quick couplings. Connecting and disconnecting them is extremely swift and the tubes used for these types of fittings are plastic (Nylon or Polyurethane).
The fitting has a seal ring inside and elastic pliers for stopping the tube. The tube is pushed up to the snubbers and the pliers, and keeps it in its place. In order to extract the tube it is necessary to push the ferrule that comes out from the fitting's top end and pull it in order to disengage the elastic pliers from the tube. The tubes employed must be calibrated.
The tubes that may be connected to the fittings have different diameters, and owing to their size, they match the fitting's threads.

Thread **M5** receives tubes with 4-5 and 6 mm external diameter
Thread **G1/8** receives tubes with 4-5-6-8 mm external diameter
Thread **G1/4** receives tubes with 4-5-6-8-10 and 12 mm external diameter
Thread **G3/8** receives tubes with 8-10-12 and 14 mm external diameter
Thread **G1/2** receives tubes with 12 and 14 mm external diameter

Fittings with all the tube sizes mentioned above are also available without threads because they are intermediate sections, and they are equipped with quick couplings at all available ports.
They may be elbow, T or Y and straight fittings with reduction of tube diameter at one of the two ports, etc.
There are several available versions for a complete range of fittings, and the materials used for their construction are metals such as brass with nickel plating surface treatments, carbon or stainless steels, and finally and more often, techno-polymers.
There are also three piece fittings that may be used with rigid types of tubes in applications where plastic tubes would be impossible.
They are made of three pieces that are the fitting body, a metal olive to be inserted at the tube's end in order to allow its sealing, and a ferrule to close it, with a base to lodge the olive, and threads that match the body's threads.
Push-in fittings are available for plastic piping. In fact, the tube is inserted into a hose shank with a swelled end. The pushed-in tube is then stopped with a tightening nut.

Chapter 13

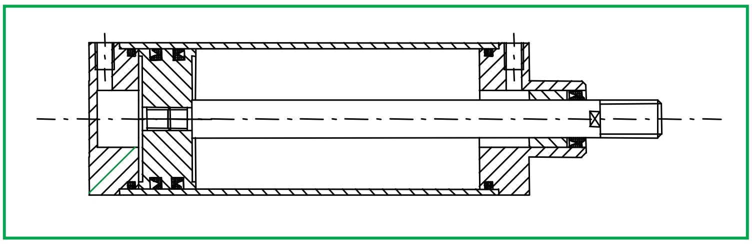
PNEUMATIC DEVICES

OPERATING PNEUMATIC ELEMENTS

The operating pneumatic elements (actuators) are the final bodies of a system that carry out mechanic work and perform many operations.
The actuators that carry out displacements or rotations with alternative movements are called cylinders.

13.1 PNEUMATIC CYLINDER FEATURES

Pneumatic cylinders, if properly sized, are devices that do not suffer overcharges, produce high speeds, may perform quick direction reversals, do not in any way influence the working environment, produce easily controlled forces and speeds, and have definite simple maintenance requirements.
They are made by a jacket (barrel) that is usually cylindrical inside a piston anchored to a rod with sealing gaskets.
On both sides of the barrel there are two closing covers. One of them has a central hole that allows the rod to come out.
The covers, defined as heads, are anchored to the barrel mechanically.



The figure shows the cylinder's configuration schematically.
The movement of the rod in both directions is activated by sending compressed air alternatively to the previous chamber or to the next chamber by means of the threaded holes on the covers connected to the two cylinder chambers.

13.2 LINEAR CYLINDERS

Cylinders are linear when they perform a rectilinear movement with their own rod, from the retracted rod position (-) to the extended rod position (+) and vice versa.
They carry out mechanic work exercising a proper force on the implementation point.
The force produced by a pneumatic cylinder stems from:

Force = Pressure x piston area

The produced force is not the same in both directions because in the return direction (-) we must deduct the area occupied physically by the rod from the piston's rated area.
The force obtained by multiplying area and pressure is a theoretical force, because we must deduct the force needed to overcome frictions from this value as well as the one needed to move the weights of both rod and piston

Frictions are caused by the friction of both the piston and rod sealing gaskets. But we must distinguish between breakout friction, known through the definition of adherence, and dynamic or sliding friction.
When the piston remains in one of two positions during a given span of time, the sealing gaskets compressed on the barrel wall and rod surface tend to expel the lubricant interposed between them and the sliding surface along the sealing generatrix. These conditions are influenced by the elastic properties of the materials (hardness and elasticity) and by the status of the surfaces (roughness). Therefore, the lubricating conditions no longer exist, and at pickup they must pass over the surfaces with almost no lubrication. Immediately after, normal hydrodynamic conditions are restored and the friction value decreases drastically.
Usually, its value decreases when the speed increases.
Moreover, at pick up the barrel suffer elastic deformations that cause resistance to motion, thus causing efficiency losses.
All this must be considered whenever choosing a cylinder, assessing that about 15% of the theoretical force is lost due to the mentioned reasons.
From the point of view in employing and using linear cylinders, we must distinguish two macro cylinder classes:

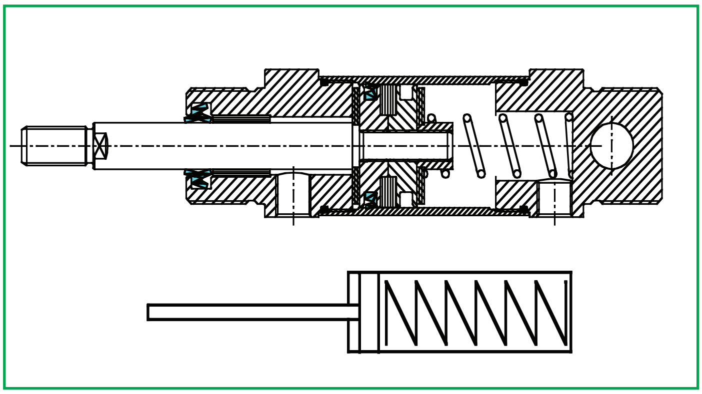
- **Single-acting**
- **Double-acting**

Substantially, cylinders include two covers, a barrel, a rod integrated to a piston, a rod guide bush and sealing gaskets for both the piston and rod, that is also equipped with a dust scraping ring.

13.3 SINGLE-ACTING CYLINDERS

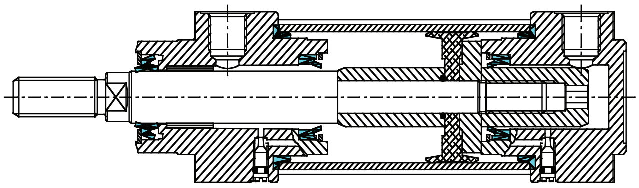
A single-acting cylinder produces its thrust in only one direction. The rod places itself in the resting position due to a spring or to an external force.
They may be divided into thrust or tension single-acting cylinders.
They are used for operations such as tightening, ejections, pressing, etc. that are performed without any loads anchored to the rod's thread.
In fact, the spring is sized only in order to reestablish the rod/piston equilibrium.

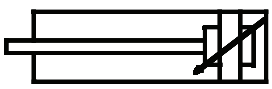
The figures reported herein show the two versions of single-acting cylinders, the first one above is the thrust type and the second one is the tension type with their respective graphic symbols.
We remind that single-acting cylinders are limited in their stroke, because the presence of the springs does not allow unlimited lengths due to their nature, and must be lodged inside the cylinder, except for certain particular cases where they have a small bore with short strokes.



13.4 DOUBLE-ACTING CYLINDERS

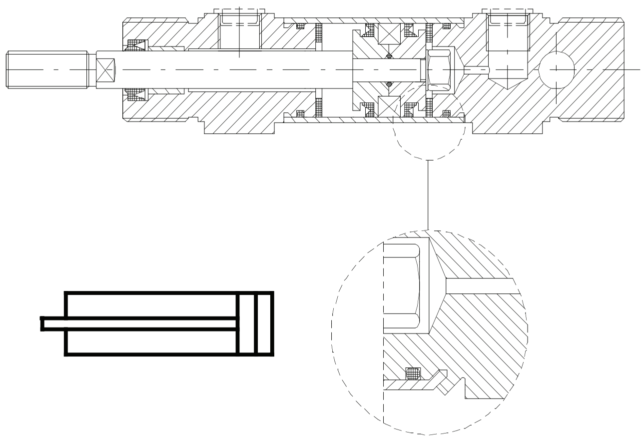
This type of actuator produces both thrust and tension forces sending pressure alternatively to the two sides of the piston. As previously said, the thrust and tension forces have different values.
They carry out different kinds of operations and, in this case, the load may be bound to the rod. It is possible to move the applied load controlling the speed easily by means of proper device sizing.
Cylinders usually have the task of stopping the load entrusted to the covers, that represent the gauge block of the stroke limiter.





Cushioned double-action with air-cushion

Cushioned double-action with elastic/rubber bumper

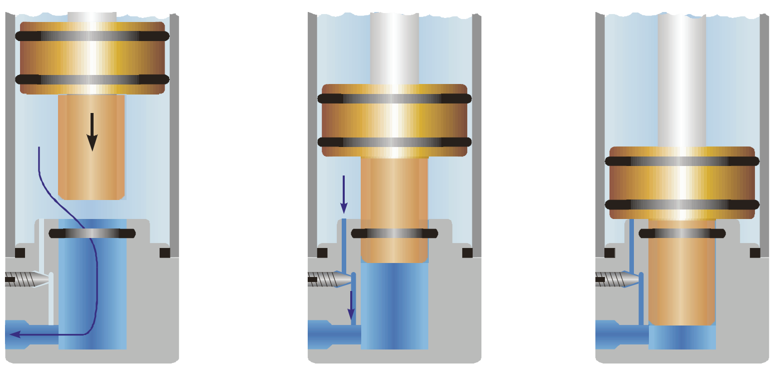


The figures show two different systems for absorbing the final kinetic energy, in order that the covers may not suffer any damages during impact.
The most effective system is made of an air-cushion that slows down the piston's stroke in the last centimeters. In small cylinders, or when the speeds involved 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



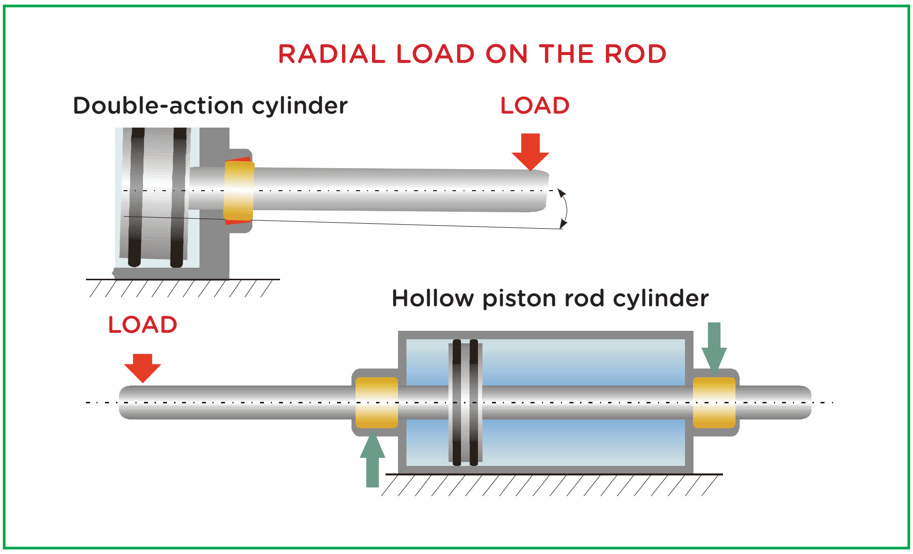
The figure exemplifies the piston while it covers the return stroke, and we can see that the escaped air flows freely from the cylinder's back chamber toward the outlet, by means of a connection threaded to the back head.
When the ogive mounted on the piston engages with the ring gasket placed on the head, free air discharges captured in the absorption chamber are prevented.
In this chamber the air is compressed by the piston's motion because it is able to flow freely toward the discharge.
In fact, it is forced toward a flow control valve before finding its natural discharge course again, and the produced pressure acts on the piston creating a force that counters the motion. Speed decreases and violent impacts on the piston head are reduced considerably.
Regulation of the absorber is obtained by acting manually on the flow control valve that makes the absorption more or less effective, according to the regulating values.
The toroidal gasket of the absorber guarantees airtightness when the air present in its own housing is pushed by the ogive in the motion's direction.
When the cylinder must reverse its motion and the previously unloaded chamber is pressurized, the gasket of the absorber, that does not have sealing functions in the opposite direction, is skirted by the compressed air that takes up the entire piston area, thus ensuring proper start-up.

13.6 CYLINDERS WITH MAGNETIC RINGS

Several methods may be used to detect cylinder piston position. One of them is to capture a proper magnetic field, outside the barrel, issued by a magnetic ring mounted on the cylinder's piston.
An external sensor is able to detect the magnetic field and can supply an electric signal that indicates its presence at that specific point of the piston.
The materials to be employed in barrel manufacturing must be necessarily non-magnetic such as aluminum, brass, stainless steel, etc. The most used material is aluminum.

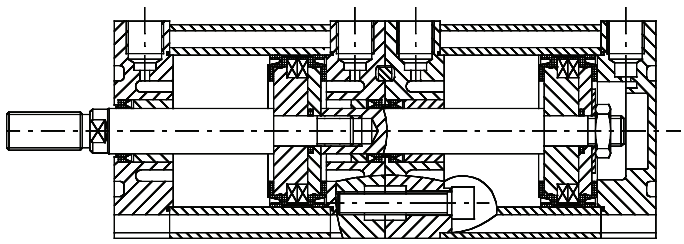
13.7 HOLLOW PISTON ROD CYLINDERS

Linear cylinders are not suitable devices to work with off-center loads or lateral loads applied to the rod. If we cannot avoid the load from acting laterally on the rod, there shall be a quick wear of the sole rod guide bushing, because the rims of its two ends are stressed by the lateral load applied. Using a hollow piston rod cylinder we distribute the lateral stress on the two guide bushings, as shown in the following figure.



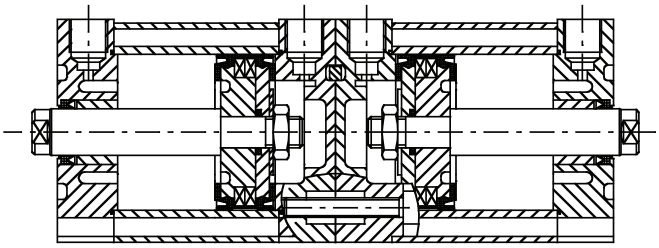
13.8 TANDEM CYLINDERS

Tandem defines an assembly made of two cylinders that have a common rod and are connected in series with each other in order to obtain a double thrust with respect to a cylinder with the same diameter. Obviously, the size in length with the same stroke is doubled.

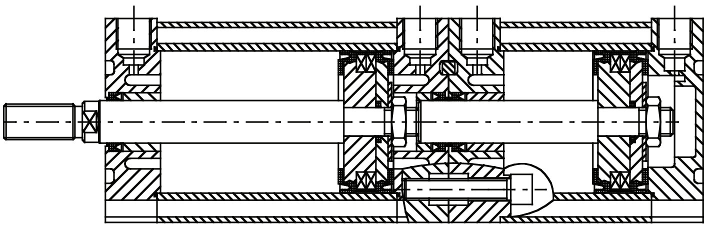


13.9 MULTI-POSITION CYLINDERS

Combining two cylinders we can obtain systems that allow accurate as well as safe repeatability positioning.
Two cylinders with equal strokes, assembled with their covers back, may assume three precise positions. With a single cylinder it would be impossible to create a system that determines three precise and repeatable positions.
With proper insight we can attempt to carry out intermediate stops, but we will encounter serious difficulties to repeat the stop always at the exact same point.

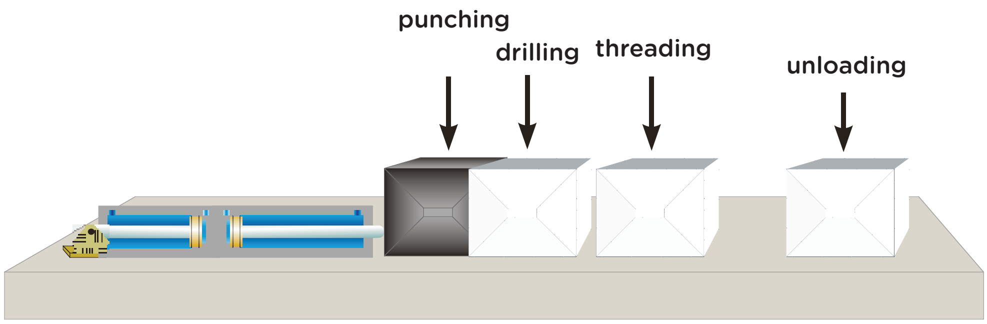


For a similar use, cylinder anchorage must be carried out with rods, and to this purpose the use of short stroke cylinders is advisable.
Additionally, two cylinders coupled in series with separate rods and different strokes may determine three positions. When the back cylinder is activated it pushes the next cylinder to its own stroke, and once it has activated the latter one, it ends its own stroke determining the final position.
For both solutions the three positions are:
1st position with resting cylinders
2nd position with one cylinder activated
3rd position with both cylinders activated



Using the solution of combined cylinders with back head but with different strokes, four different positions may be obtained, as shown in the following figure.

EXAMPLE OF USE OF A MULTI-POSITION CYLINDER

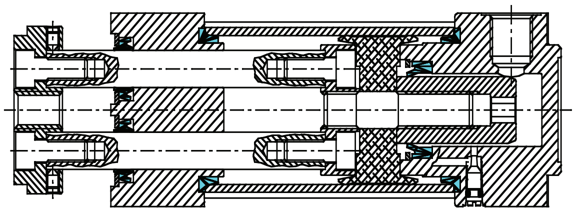


13.10 OVAL AND SQUARE CYLINDERS

Linear cylinders with circular sections may be subjected to rod rotation during the stroke. Sometimes this must be avoided, and the use of actuators with oval and square sections solves this problem.
In particular, the oval cylinder has a flat shape and in certain situations it may solve space problems.
The non-rotating function of the rod is determined by the barrel's shape and piston section, and certain movements, which depend on the coupling barrel/piston exclusively, are allowed within certain limits.

13.11 TWIN ROD CYLINDERS

For more accurate non-rotating functions, cylinders with two parallel rods coupled to the same piston can be used. A connecting plate joins the two rods in the external part. The load to be moved is connected to this plate.
Optimal non-rotating operation is thus obtained and, moreover, this kind of cylinders can support discrete lateral loads.

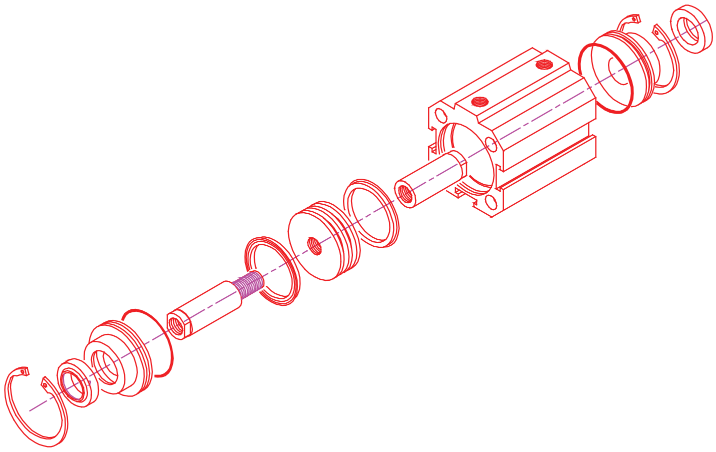


Obviously, there are other methods to implement non-rotating systems, such as the use of hexagonal rods coupled to a similar guide bushing and to a sealing gasket with the same shape. Usually, these systems are applied to micro-cylinders.

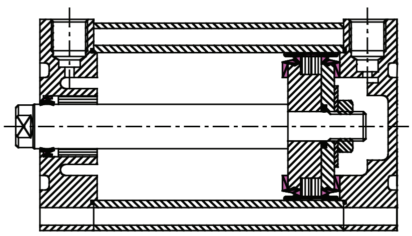
13.12 SHORT STROKE CYLINDERS AND COMPACT CYLINDERS

As their name defines, short stroke cylinders have been manufactured in order to carry out short strokes, precisely due to the way they have been designed.
They are used in small spaces and due to their reduced sizes, insertion of proper guides on the rod is not allowed.
Therefore, they cannot support lateral loads. Even small stresses in that

direction could cause then guide bushings to stick and wear out quickly. In these cylinders, the covers are represented by two discs retained inside the extruded rod profile by two rubber rings.



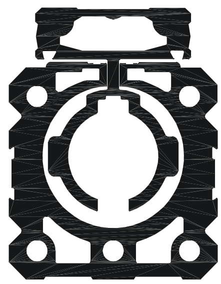
Compact cylinders have been created later than short stroke cylinders, with the purpose of inserting a cylinder that may represent the evolution of the short stroke cylinder.
Their heads, even if they have reduced sizes, are equipped with rod guides and are anchored to the extruded body by means of screws.
This assembly results to be more rigid.

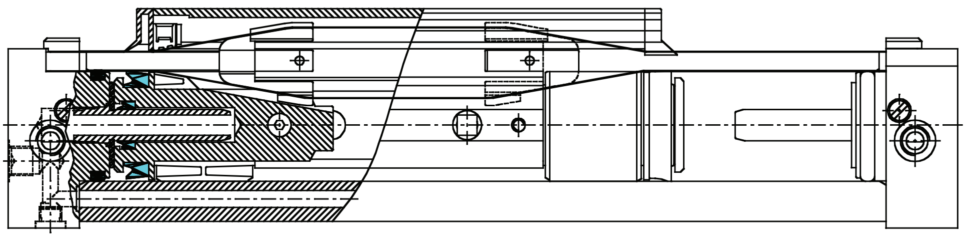


Actually, the total size of the compact cylinder is larger than the ones of the short stroke cylinder. For this reason, the two versions are still present in the market and one does not substitute the other.
The compact cylinder, contrary to the short stroke cylinder, was developed from the beginning with its size in mind by the French national unification entity (UNITOP) according to the choice of the first manufacturer who produces it, and this allows interchangeability between different manufacturers.
Some manufacturers have also inserted an ISO version that actually unifies the fixing dimensions of the accessories that are thus useable in different cylinder series.
With this in mind, the final end user is able to order smaller quantities of cylinders and accessories.

13.13 RODLESS CYLINDERS

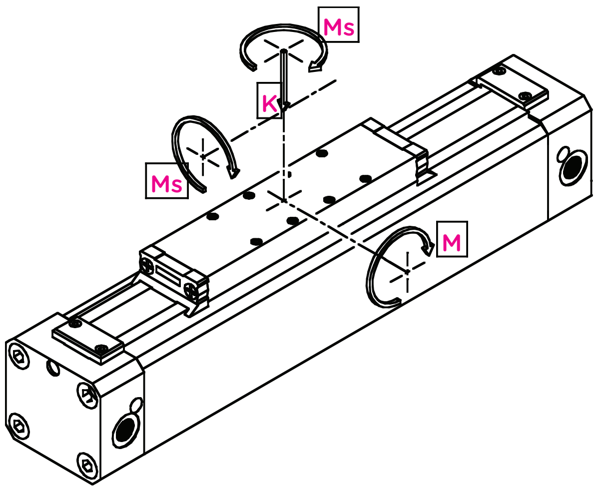
The rodless cylinder is a device that requires particular attention whenever used, because in contrast to the traditional cylinders, where the load is placed in line with the rod, in the rodless cylinder the weight is anchored on a carriage that runs on the top part of the cylinder, and between the cylinder axis and the load's barycentre there is always a more or less accentuated arm according to the shape of the object to be moved.





The piston's force is transmitted to an external carriage by a mechanic arm that comes out from an opening located in the barrel along the entire stroke and is connected to the piston solidly. Sealing is guaranteed by an internal metallic strap fixed at the ends of the body that completely covers the opening. The piston's gaskets, their internal pressure and a magnetic band properly positioned make the metallic plate adhere to the internal surface of the tube, ensuring sufficient outward sealing and also between the two cylinder chambers.
A further metallic strap placed outside, in correspondence with the opening, prevents dust collection in the sliding areas. Sealing in this type of cylinder is never perfect. Particular guide systems obtained on the carriage and on the piston, open the two plates in order to allow mechanic connection between piston and slider/cursor. In opposition to rod cylinders, the forces expressed by the cylinder in the two directions are identical. In fact, there is no difference in sections on the two sides of the piston since the rod does not exist. The regulating air-cushion absorption function is exactly identical to the one performed in the rod cylinders.

When designing rodless cylinder systems we must pay particular attention to the generated kinetic energies, because remarkable transfer speeds (2 to 3 m/sec) and definitely large strokes (up to 6 meters) may be reached.
Moreover, the load may be positioned with its own barycentre out of the carriage's gravity center producing bending moments.
We must be reminded that these moments are the product of a force expressed in N (Newtons) for an arm measured in m (meters). Therefore, the measuring unit for a given moment is the Nm (Newtons x meter).



Once the cylinder with sufficient thrust has been identified, we must assess the position of the load on the cursor, and identify the moments that may be involved. The following table points out the maximum loads and moments that are admitted under static conditions.

Diameter (mm)	Load max, K N	Moment max M (Nm)	Moment max Ms (Nm)	Moment max Mv (Nm)
25	300	20	1	4
32	450	35	3	6
40	750	70	5	9
50	1200	120	8	15
63	1600	150	9	25

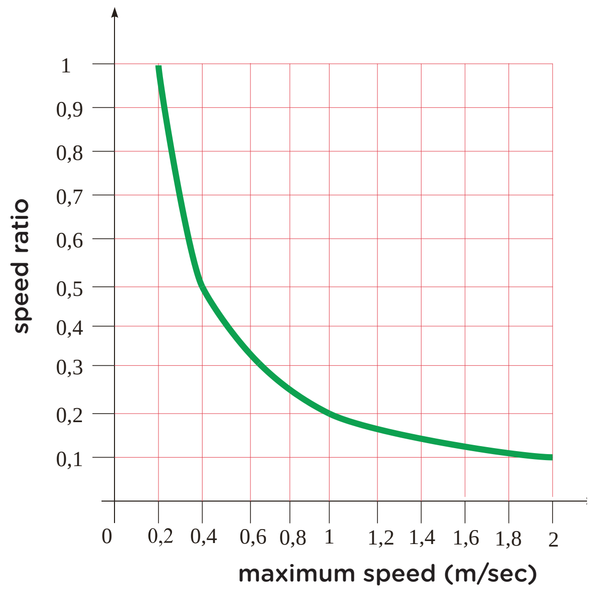
Now we must considerer the speed of the carriage that has to be preferably equal to 1 m/sec, and look at the following diagram in order to know the maximum load K under dynamic conditions. In transfers with speeds up to 0.2 m/sec there will be no problems, but if the speed increases, the applied load must be reduced, or the size of the cylinder must be increased.

The permissible dynamic load depends on the speed, and results from:

Kd = K x Cv

Where Kd is the dynamic load and Cv is the speed ratio. If in static conditions a cylinder admits 750 N, with operating speeds equal to 0.5 m/sec the load must be reduced to 750 x 0.4 = 375 N.

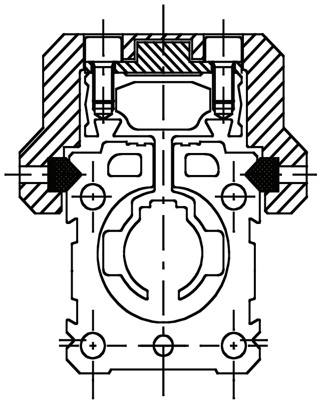
**RODLESS CYLINDER - INTERNAL GUIDE
SPEED RATIO**



In case of combined stresses, or rather with moments that act simultaneously, the following equation may be useful:

$$\left[\left(\left[\left(2 \cdot \frac{M_s}{Ms\,max}\right) + \left(1{,}5 \cdot \frac{M_v}{M_v max}\right) + \left(\frac{M}{M max} + \frac{K}{K max s}\right)\right] \cdot \frac{100}{K_v} \leq 100\right.\right.$$

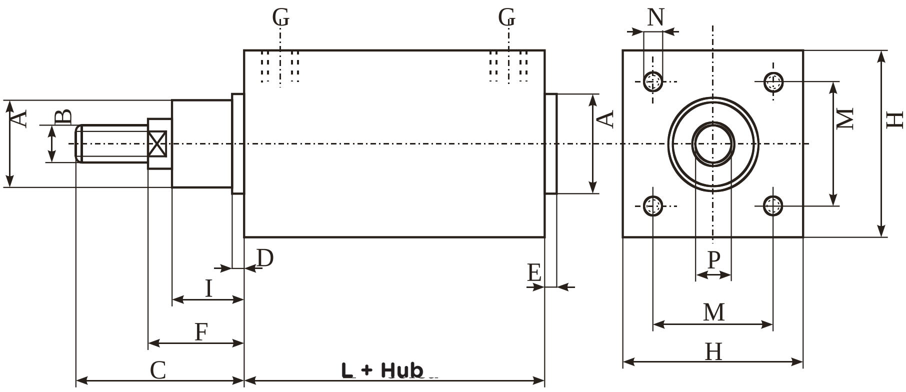
In case of tougher stresses, accessories such as external linear guides may be applied to the cylinders to which the load is anchored, making the cursor to carry out the dragging task, or rather; additional guides may be mounted on the existing carriage.



13.14 FIXING STANDARD AND COMPONENTS

According to international law, the ISO unification institution has issued standards that regulate the basic sizes of certain cylinders.
This standardization allows complete interchangeability of cylinders manufactured by different manufacturers, offering easy replacement availability and a large choice of suppliers of machine manufacturers.
ISO 6432 tables standardize basic micro-cylinder sizes with bores included within O8 and O25. (ISO = international standard organization)
For cylinders with larger diameters, from 32 to 320, ISO 15552 (ex ISO 6431-VDMA 24562) standards are enforce.

SIZES OF CYLINDERS AND RODS D.E. S.E.

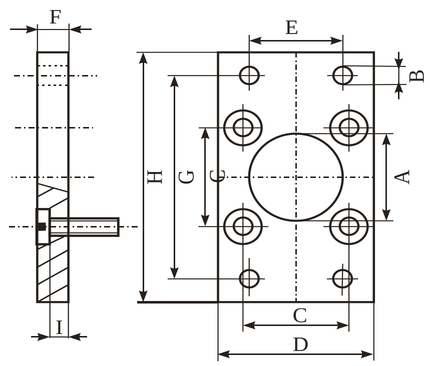


The figure shows, for example, the sizes of different diameters to be respected for pneumatic cylinders subjected to ISO 15552. All the standards are available at the unification national institution UNI.
In addition to the sizes of the basic cylinder, there are tables, acknowledged by ISO and released by national unification institutions such as DIN (German unification institute) that, except for different agreements with the customer, indicate the cylinder stroke tolerances.

	Cylinder Internal bore (Diameter) in mm	Stroke in mm	Stroke tolerance in mm
DIN ISO 6432	8, 10, 12, 16, 20, 25	up to 500	+1,5
DIN ISO 6431	32, 40, 50	up to 500 over 500 up to 1250	+2 +3,2
	63, 80, 100	up to 500 over 500 up to 1250	+2,5 +4
	125, 160, 200, 250, 320	up to 500 over 500 up to 1250	+4 +5

We can see that tolerances referred to strokes are always followed by plus signs. Additionally, fixing accessories such as flanges, pins, hinges and similar are necessarily subjected to size bounds in order to allow their perfect interchangeability.

FIXING FRONT FLANGE



The figure shows the binding dimensions of the front flange as an example.
Other types of cylinders, as has been mentioned, follow French national standards such as UNITOP, and this is the case of compact cylinders with bores going from Ø12 to 100.
Additionally, cylinder bores are standardized in accordance with the following schedule. For ISO 6432 micro-cylinders: Ø 8 - 10 – 12 – 16 – 20 - 25.
For ISO 15552 cylinders: Ø 32 – 40 – 50 – 63 – 80 – 100 – 125- 160 – 200 – 250 – 320.
Also, any cylinders not subjected to regulating bounds maintain the same rates, for example, for short stroke cylinders, body diameters are Ø 20 – 25 – 32 – 40 – 50 – 63 – 80 – 100.
Linear sizes and diameters are expressed in mm.

13.15 STROKE LIMITER SENSORS

When a pneumatic cylinder has carried out its stroke, in many cases, this operation must be indicated by sending a signal in order to authorize a later working phase.
To this purpose, certain signaling methods exist that we shall define as “real” or “virtual” signaling.

Real signaling

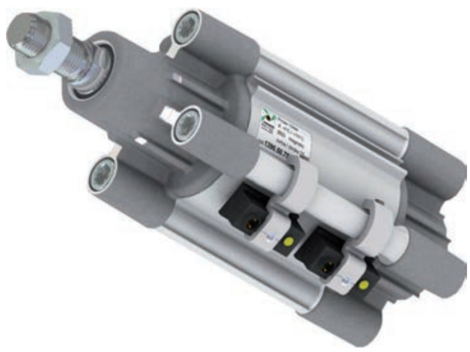
- As has been already said, a permanent magnet is inserted into the cylinder’s piston, which sends a magnetic field outwards that is received by a sensor able to close an electric contact, and send the stroke limit signal. The barrel must be manufactured with non-magnetic materials.
- The cylinder rod activates an electric contact or a pneumatic valve mechanically in order to release the stroke limit signal.

Virtual signaling

We shall consider the status of an unloaded cylinder chamber whenever it may have carried out the entire stroke. The piston has completed its stroke when the unloaded chamber reaches a gauge pressure near to zero. This condition is recognized by a valve that proceeds to send a pneumatic signal indicating that the operation has been performed. In case of virtual signaling, the near to zero pressure condition may appear even when the piston has not completed the stroke, due to external factors that block its progress. In this case, the valve will release an incorrect signal.

Magnetic stroke limit sensors

Sensors that detect magnetics fields indicate the piston’s position by means of a magnetic field created by the magnet. These sensors are fixed on the cylinder barrel by using specific fixing clamps, or they are inserted in slots casted into the barrel.

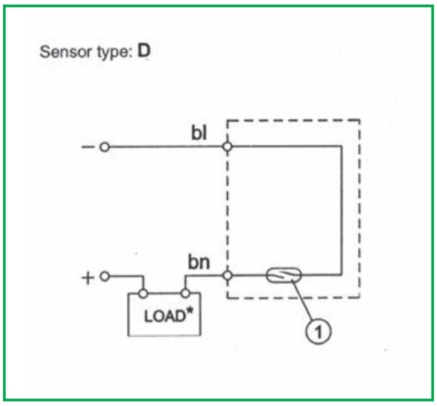


There are many devices that detect the presence of a magnetic field, the most common being reed contact sensors and electronic sensors, among which the most known one is the HALL-effect sensor.

Ampoule reed sensor

Ampoule reed magnetic sensors include a small glass ampoule where two thin plates are placed in absence of air, and, once they are immersed in a magnetic field, they attract each other closing the electric contact.

According to their sizes, they may offer different energy values and they do not need their own feeder.

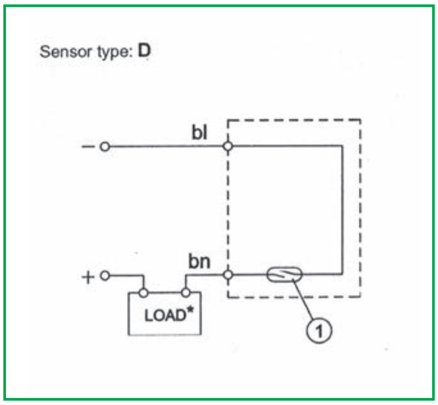


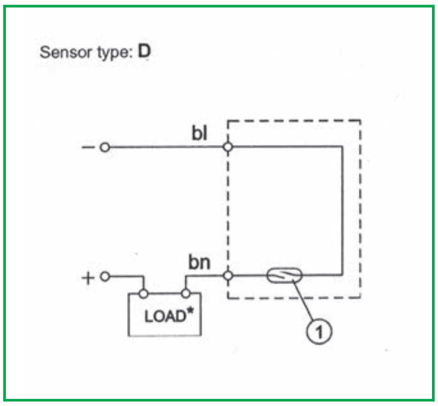
In the diagram, the ampoule is the particular 1 and it must always be connected in series to the applied load (LOAD). It may work both under direct and alternating currents respecting the allowed voltage and current values.
They are two-wire sensors, and the load may be connected indistinctly to the positive or negative poles. In alternating currents, the connection may be carried out without considering this polarization. In presence of direct current Led lights the polarity must be respected, otherwise the Led shall not turn on.
Each sensor with its Led, fed by a diode, has its own voltage drop (2 to 3 Volts) and when they are connected in series their individual drops are added up, and sometimes the PLC may interpret the voltage value incorrectly.
Moreover, the sensors may be equipped with specific protections called varistors, which have the function of protecting it by means of the reverse voltage produced by the electro-valve coils, or by the relay when the ampoule's contact is opened.
When the sensors are connected in series we can use three-wire sensor reeds in order to avoid voltage drops, where the Led is not powered by the diode that should cause the drop, but directly by 24 Volts that is the maximum admitted voltage value.

HALL-effect sensor

When a conductor or semiconductor with an electric current is immersed in an external magnetic field, it produces weak potential differences (voltage).
This physical effect is known by the name of "Hall Effect". There are particular electronic switches that use the Hall Effect, which become active in presence of a sufficiently large external magnetic field (they close up electrically).
The Hall Effect sensor includes one of these magnetic switches.
Since the presence of currents that cross the conductor or semiconductor is always required, it must necessarily powered be with direct voltages. This implies that the Hall Effect sensors are three-wire sensors, and they may be powered with alternating current. Since the electronic switch has a structure comparable to the structure of a transistor, no moving metallic contacts are present. This causes lack of mechanic wear, and therefore, this sensor has a notably higher lifetime than those sensors using REED ampoules.

Depending on the particular type of electronics connected to the magnetic switch, there are Hall Effect sensors where the output of the sensor (black wire) is:
- Internally connected to the positive signal (brown wire): PNP, left figure;
- Internally connected to the negative signal (blue wire): NPN right figure.





Moreover, Hall Effect sensors are also divided based on their behavior in relation with the presence of an external magnetic field. In particular, the sensor allows:
- The passage of current only in absence of the magnetic field N.C. (normally closed)
- Passage of current only in presence of a N.O. (normally opened) magnetic field.

Please note: the electronic circuit connected to the switch introduces a voltage drop. Particular attention must be paid whenever using many sensors in series due to this drop.

The diagrams show the different load (LOAD) connections for the two versions.

13.16 CYLINDER SIZING

When choosing a Pneumatic cylinder certain aspects need to be kept in mind by the designer, all the parameters that we are now about to evaluate must be considered.

Produced force

A cylinder produces a force that is calculated considering the piston area and the pressure that affects it.

F(daN)= area (cm2) x pressure (bar)

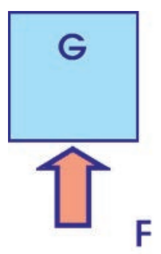
Ø Cylinder	Ø Piston rod		Pressure (bar)									
			1	2	3	4	5	6	7	8	9	10
8	4	Force F	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0
		Tensile force F	0,4	0,8	1,1	1,5	1,9	2,3	2,6	3,0	3,4	3,8
10	4	Force F	0,8	1,6	2,4	3,1	3,9	4,7	5,5	6,3	7,1	7,9
		Tensile force F	0,7	1,3	2,0	2,6	3,3	4,0	4,6	5,3	5,9	6,6
12	6	Force F	1,1	2,3	3,4	4,5	5,7	6,8	7,9	9,0	10,2	11,3
		Tensile force F	0,8	1,7	2,5	3,4	4,2	5,1	5,9	6,8	7,6	8,5
16	6	Force F	2,0	4,0	6,0	8,0	10,1	12,1	14,1	16,1	18,1	20,1
		Tensile force F	1,7	3,5	5,2	6,9	8,6	10,4	12,1	13,8	15,6	17,3
20	8	Force F	3,1	6,3	9,4	12,6	15,7	18,8	22,0	25,1	28,3	31,4
		Tensile force F	2,6	5,3	7,9	10,6	13,2	15,8	18,5	21,1	23,8	26,4
25	10	Force F	4,9	9,8	14,7	19,6	24,5	29,5	34,4	39,3	44,2	49,1
		Tensile force F	4,1	8,2	12,4	16,5	20,6	24,7	28,9	33,0	37,1	41,2
32	12	Force F	8,0	16,1	24,1	32,2	40,2	48,3	56,3	64,3	72,4	80,4
		Tensile force F	6,9	13,8	20,7	27,6	34,6	41,5	48,4	55,3	62,2	69,1
40	16	Force F	12,6	25,1	37,7	50,3	62,8	75,4	88,0	100,5	113,1	125,7
		Tensile force F	10,6	21,1	31,7	42,2	52,8	63,3	73,9	84,4	95,0	105,6
50	20	Force F	19,6	39,3	58,9	78,5	98,2	117,8	137,4	157,1	176,7	196,3
		Tensile force F	16,5	33,0	49,5	66,0	82,5	99,0	115,5	131,9	148,4	164,9
63	20	Force F	31,2	62,3	93,5	124,7	155,9	187,0	218,2	249,4	280,6	311,7
		Tensile force F	28,0	56,1	84,1	112,1	140,2	168,2	196,2	224,2	252,2	280,3
80	25	Force F	50,3	100,5	150,8	201,1	251,3	301,6	351,9	402,1	452,4	502,7
		Tensile force F	45,4	90,7	136,1	181,4	226,8	272,1	317,5	362,9	408,2	453,6
100	25	Force F	78,5	157,1	235,6	314,2	392,7	471,2	549,8	628,3	706,9	785,4
		Tensile force F	73,6	147,3	220,9	294,5	368,2	441,8	515,4	589,0	662,7	736,3
125	32	Force F	122,7	245,4	368,2	490,9	613,6	736,3	859,0	981,7	1104,5	1227,2
		Tensile force F	114,7	229,4	344,0	458,7	573,4	688,1	802,7	917,4	1032,1	1146,8
160	40	Force F	201,1	402,1	603,2	804,2	1005,3	1206,4	1407,4	1608,5	1809,6	2010,6
		Tensile force F	188,5	377,0	565,5	754,0	942,5	1131,0	1319,5	1508,0	1696,5	1885,0
200	40	Force F	314,2	628,3	942,5	1256,6	1570,8	1885,0	2199,1	2513,3	2827,4	3141,6
		Tensile force F	301,6	603,2	904,8	1206,4	1508,0	1809,6	2111,1	2412,7	2714,3	3015,9
220	50	Force F	380,1	760,3	1140,4	1520,5	1900,7	2280,8	2660,9	3041,1	3421,2	3801,3
		Tensile force F	360,5	721,0	1081,5	1442,0	1802,5	2163,0	2523,5	2884,0	3244,5	3605,0
250	50	Force F	490,9	981,5	1472,6	1963,5	2454,4	2945,2	3436,1	3927,0	4417,9	4908,7
		Tensile force F	471,2	942,5	1413,7	1885,0	2356,2	2827,4	3298,7	3769,9	4241,1	4712,4
320	63	Force F	804,2	1608,5	2412,7	3217,0	4021,2	4825,5	5629,7	6434,0	7238,2	8042,5
		Tensile force F	773,1	1546,1	2319,2	3092,3	3865,4	4638,4	5411,5	6184,6	6957,7	7730,7

In a double-acting cylinder, this is valid for both the outlet stroke and the inlet stroke. The thrust force produced by a double-acting single-rod cylinder is not the same in both directions. In the return stroke (retraction), the piston's surface is affected and the pressure is lower than the thrust surface, due to the presence of the rod on that side, the rod area must be deducted from the piston's area.
The table described in the previous page shows the theoretical forces produced by the cylinders at different pressures in both directions, also showing the rod's diameter.
We must always deduct 10 to 15% of the total theoretical force values due to head losses produced by gasket frictions.
In the first instance, we must know the weight of the applied load, and choose a cylinder that produces enough force to move in the desired direction, paying attention to the load ratio, which may not be higher than 70%. Load ratio is understood to be that the weight to be moved has a maximum value equal to 70% respect to the force produced by the cylinder, including any losses.
Any available force in excess shall be used to accelerate the load.

$$\frac{\textbf{Required force}}{\textbf{Available force}} \times 100$$

Now we must know what the cylinder's working position is, if it works vertically with upward or downward thrusts, or if it works on a horizontal or sloping plane.

Vertical lifting



G = applied load
F = cylinder thrust

The total force needed to lift the load shall be:

$$F = FG + Fa$$

Where FG is the force used to balance the load or resisting force, and Fa is the force needed to accelerate it.
In addition, we must know what the actuating speed is, in order to establish the magnitude of Fa.
For example, should we lift a mass equal to 120 Kg for a 400mm movement (cylinder stroke) with a final speed equal to 1 m/sec, we should calculate what shall be the total final force produced at a respective 6 bar operating pressure.

We remind that a force F is equal to a mass for acceleration, and that the work L is equal to a force for a movement, which is equal to the kinetic energy.

$$F = m \times a \qquad L = F \times S = 1/2\ m\ V^2 \quad (1)$$

m = mass in Kg
a = acceleration in m/sec2
S = movement in m
V = speed in m/sec
g = gravity acceleration 9.81 m/sec

Therefore:

$$FG = mg$$

The total force shall be:

$$F = mg + Fa \quad (2)$$

From (1) we can go back to Fa, because we know the actuating speed equal to 1 m/sec, the mass to be lifted is 120 Kg and the cylinder's stroke is 0.4 m.

$$Fa \times 0{,}4\ (S) = \frac{120\ (m)}{2}\ 1^2\ (V)$$

$$Fa = \frac{60}{0{,}4}\ 1 = 150\ N$$

Return now to (2):

$$F = mg + Fa = (120 \times 9{,}81) + 150 = 1327{,}2\ N\ (132{,}7\ daN)$$

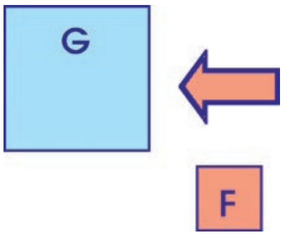
From the table where the forces produced by the cylinders are described, at a 6 bar pressure thrust, we will choose the cylinder by deducting 15% from the theoretical force.
The cylinder chosen shall be the Ø 63 that expresses a real force of 159 from N to 6 bars. We will be forced to use flow regulators, in order to limit the speed because the available force needed to reach 1 m/sec is excessive.
If the load should perform a reversed and descending movement, we must deduct the resisting load's weight from the accelerating force and therefore:

$$F = Fa - mg$$

Unequivocally, the force F shall have a negative sign. This means that the weight's force instead of opposing the movement assists it, and increases the force that produces acceleration. We shall use flow regulators in order to limit speeds.

Horizontal load

Instead, when the load is supported and the working position is horizontal, the resisting force that presses on the plane must be multiplied by the friction ratio.
This ratio changes according to the materials that enter into contact.



$F = Fa + \mu\, mg$

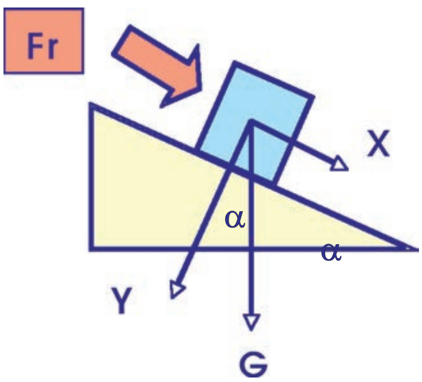
If we considered that the average value of the friction ratio μ is equal to 0.1, the total force F shall be clearly lower because:

$$F = 150 + 0{,}1\,(120 \times 9{,}81) = 267{,}72\ N\ (26{,}772\ daN)$$

In this case, a Ø 32 cylinder should be more than sufficient.

Load on sloping planes

All the other positions may be assimilated to the movement of a body on a sloping plane, and their sizing must be carried out using trigonometry rules. Also, in this case we must consider the friction ratio μ between the load and the slider bed. The resisting force Fr results from:



$Fr = \mu\, Fy + Fx$

But: $Fx = FG \sin\alpha$ and $Fy = FG \cos\alpha$, therefore:

$$Fr = \mu\,(FG \cos\alpha) + FG \sin\alpha$$

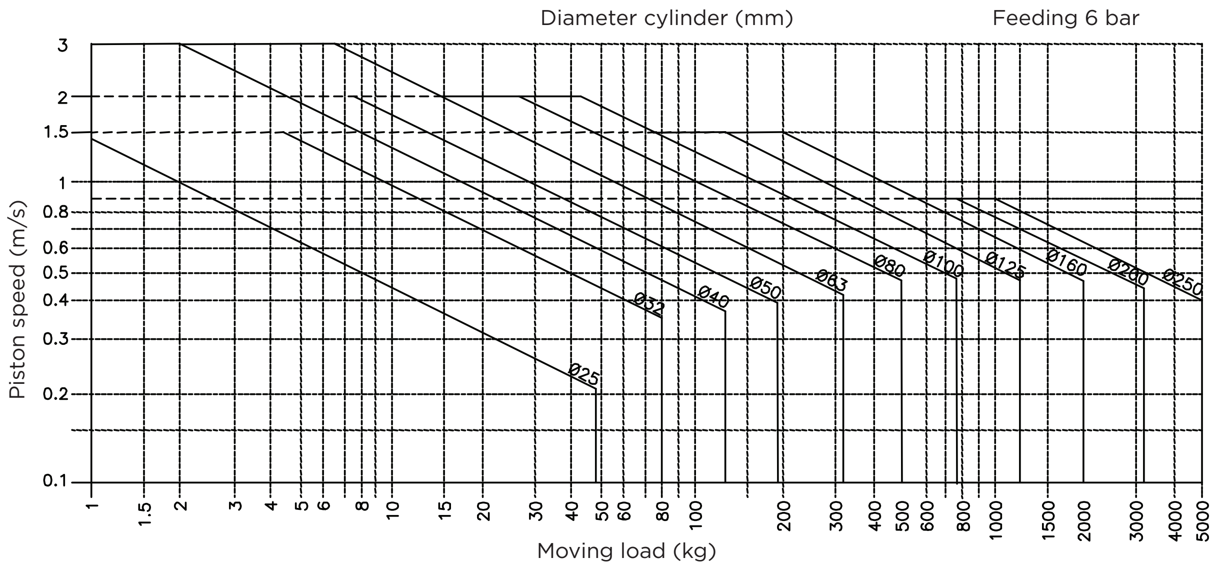
In order to calculate the total force, what has been said in the previous paragraph is valid.

Cushioning: absorption capacity

The regulating air-cushion absorption, as previously explained, has the task of absorbing the kinetic energy at the end of a cylinder stroke in order to avoid collisions against the covers. The kinetic energy to be absorbed corresponds to the work performed and is measured in J (Joule).
Once the cylinder has been chosen in accordance with its thrust, speed and working positions, we must verify that its absorption capacity is able to slow down the load. If we know the mass in Kg and the speed in m/sec, we can easily calculate the kinetic energy using the known formula:

$$Ec = 1/2\ mV^2$$

The calculated value shall be compared with the technical data provided by the manufacturers in their data sheets, in order to verify their applicability. Sometimes, certain diagrams from which we can verify the right cylinder size if we know the mass, speed and operating pressure, are available in these technical datasheets.



All the points referred to mass and speed that are inside the included area of each cylinder are to be pondered correctly to ensure proper absorber operation.
Now let's verify, for example, the data calculated to use the cylinder in a vertical position that, with a 63 mm bore, moves a mass equal to 120 Kg at a 1 m/sec speed.
If we combine the known values in the diagram, we can see that the point falls out the area contained by the Ø 63; this means that in similar conditions, the cylinder would not support the collisions. We must choose a cylinder able to absorb them; in our case, an 80 mm bore shall be scarcely enough.

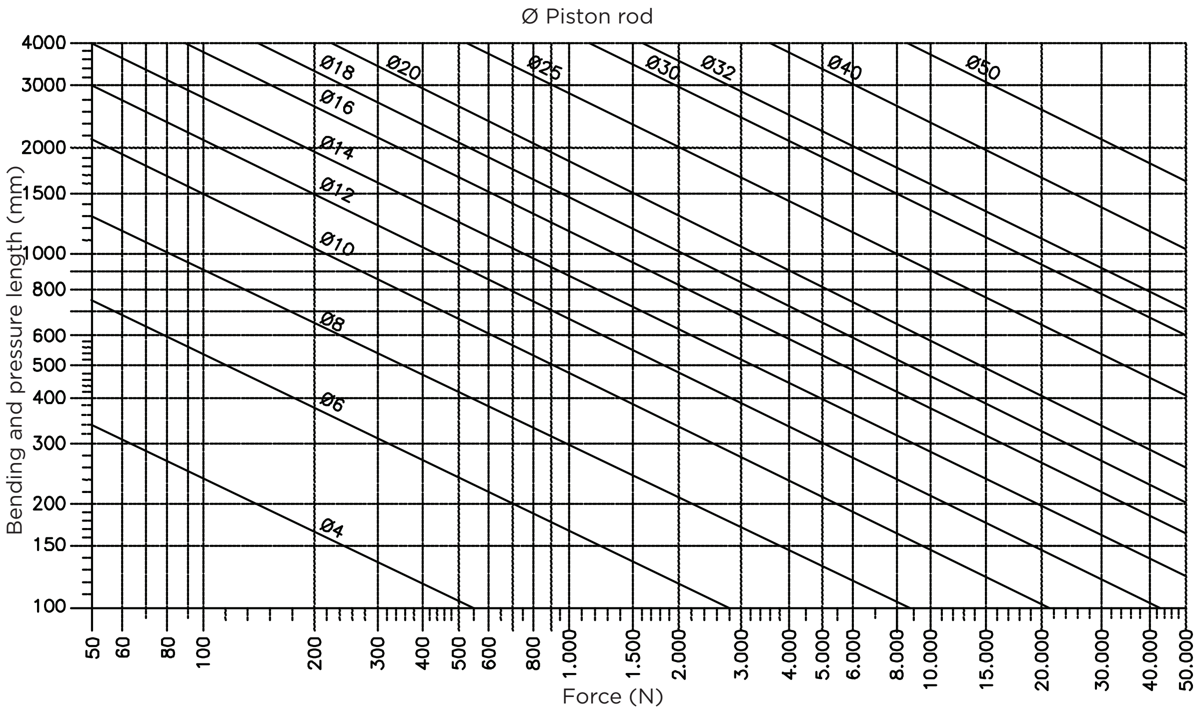
Buckling load

The buckling load is the stress exerted by compressive and flexural forces that appear on a rod, in our case of a cylinder, of certain slenderness when it is loaded with a compressing force that coincides with its own axis.
The appearing effect is a lateral flexion. The magnitude of this flexion depends on:

- The load applied
- The rod's length and diameter
- The type of constraint applied

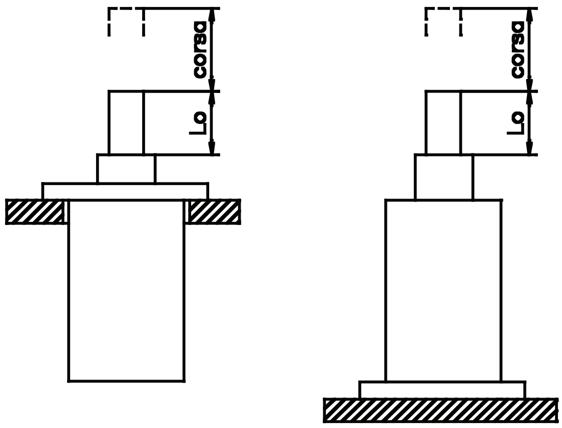
The generic calculation method uses Euler's formula, but use of easy interpretation diagrams is much more immediate.
The most critical insertion block is a cylinder constrained with pivots at both ends.

With all other fixings, the allowed loads are greater than 50%.
The following diagram shows the maximum length for different rated rod diameters allowed between the two insertion blocks, in order use a slim system within the limits allowed according to the applied load.
In the case considered, the maximum system length to be verified is the one of a cylinder that has its rod extracted completely.

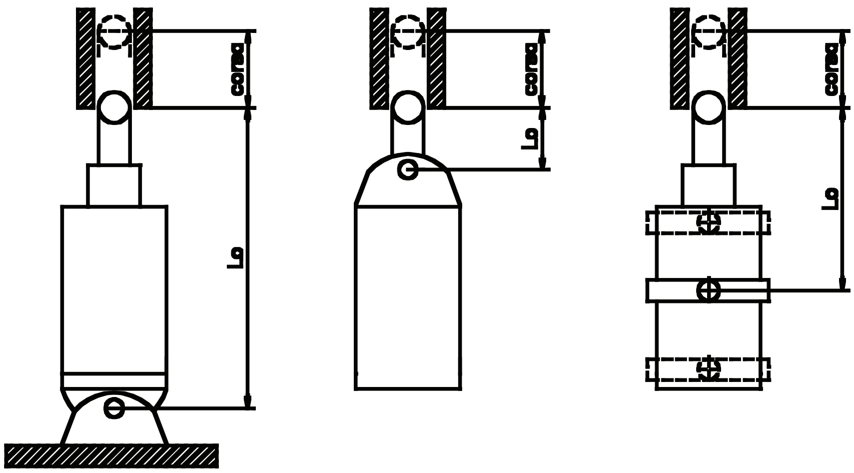


The crossing points between force and length that fall inside the area delimited by the diameter of the respective rod have to be considered correct.
The following figure shows all the insertion block variants and their respective compression lengths and flexion to be considered (Lo + stroke).

SITUATION A



SITUATION B



Lateral load

The lateral force supported by a cylinder rod depends almost exclusively on how much the rod protrudes. It is evident that the larger the stroke, the longer it shall protrude.

It is known that pneumatic cylinders do not support similar stresses well, but we can calculate their value approximately with the following ratio:

$$F = 0{,}085 \frac{Fp \times l}{l + L + c}$$

Where:

Fp = thrust force of the piston at 6 bars
l = minimum distance between the piston's centerline and the rod's guide
L = minimum distance between load application point and the rod's guide
c = piston stroke

The distances l and L are dimensions that must be required from the cylinder's manufacturer.

Operating temperature and contaminants

A last point that deserves attention is the environment in which the cylinder shall operate.
We must always consider the operating temperature that in standard equipment may be from -5°C to +70°C, in order to use the correct mixtures for sealing gaskets and lubricating greases.
In case of temperatures higher than +70°C or lower than -5°C, it will be necessary to consult the manufacturer who shall indicate the right solution for each case.
In particular environments, as for example paint booths, the equipment may possibly enter into contact with contaminants emitted by the processing materials present in the environment, or even in the distributed compressed air.
This could damage the sealing gaskets affecting the entire system's operation.
This matter shall be treated hereinafter in the chapter dedicated to sealing elements.

Consumption

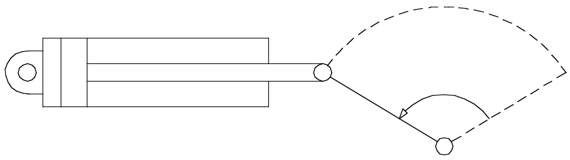
The air consumption of a cylinder is defined as:

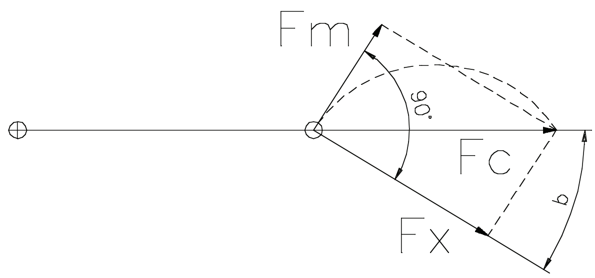
Piston area x stroke x No. of single strokes per minute x absolute pressure

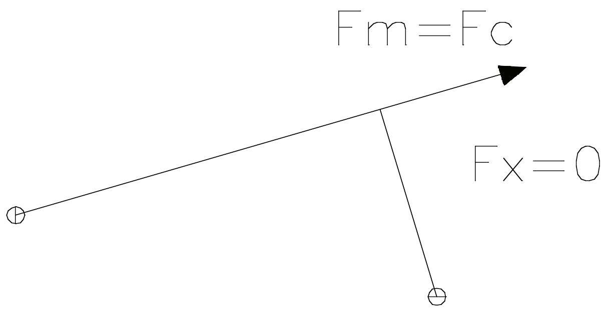
Considering that for single-rod cylinders we must deduct the area occupied by the rod from the piston area during the return stroke.
A corrective factor K = 1.2 that multiplies the calculated value is always used in order to compensate the volume transformation phenomenon due to expansion heat losses that occur quickly when a valve is opened to discharge compressed air to the atmosphere. This consumption is measured in liters.

13.17 ROTARY ACTUATORS

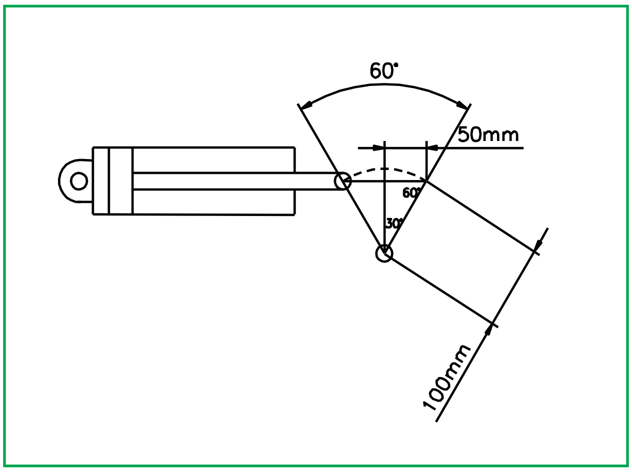
In many applications there is a need to transform a linear movement into an angular one, in order to transfer certain objects by means of rotation. The rotation angle may vary. For angles up to 90° we can use a constrained linear cylinder with junctions at its ends that activate a lever, with the same insertion blocks/junctions, and that transforms the linear stroke into a rotatory angle.
The figure shows the application schematically, and denotes the factorization of force Fc produced by the cylinder in the two components Fm and Fx.
Fm is the component that shall activate the lever, and Fx is the non-active component lost for compression on the lever.







The component Fm shall be equal to Fc with Fx = 0 when the lever is perpendicular to the cylinder's axis. During the remaining rotation, Fx works in traction with respect to the lever. Let's presume that we must size our cylinder in a similar situation.
We want a 100mm long lever to perform an angular course equal to 60°, and the moment to be overcome is equal to 20 Nm. The operating pressure is 6 bars.



To counterbalance a 20 Nm moment requires:

20 Nm / 0.1 m = 200 N (Moment / lever length in m)

Therefore, the total force Fc of the cylinder shall be:

200 N / sen 60° = 200 / 0.866 = 231 N (23.1 daN)

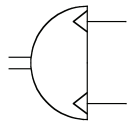
Now, we are able to calculate the piston's area since we know the necessary force and operating pressure:

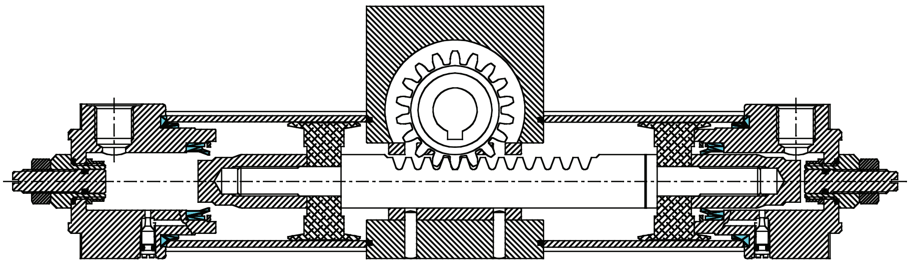
Area = Force / Pressure = 23.1 / 6 =3.85 cm²

This corresponds to a 22.14 mm diameter circumference.
For the time being, the cylinder we should consider is Ø 25. But we know that the load ratio must not be greater than 70%, and that leads us to choose the Ø 32. Now let's calculate the stroke, defining the string that subtends the circumference arc directly in mm:

(Lever length x sen 30°) x 2 = (100 x 0.5) x 2 = 100 mm

A cylinder called rotary actuator is used instead, in order to allow greater rotation angles.
There are devices equipped with pinion/rack mechanisms, as shown in the figure described on the next page.
The shaft that comes out from the central block is connected to a pinion that engages on a rack moved alternatively by two pistons. A torque is thus produced, whose magnitude depends on the actuator's size and on the operating pressure.
Sizing of this device is performed considering its rotation speed and actuating angle. In presence of slow rotation speeds (90° in more than 2 seconds) the torque produced is the main value to be considered if we know the mass and the application radius. Otherwise, if the rotation is carried out quickly (90° in less than 1 second) it is necessary to pay attention to the kinetic energy that is to be reduced.





In fact, when a mass fixed to an arm is accelerated, the kinetic energy is the dominant parameter. In this type of uses we must not consider the mass in Kg as we do in linear movements, but we must consider the moment of inertia in N/m2, that in the formula of the energy shall substitute the mass. In a rotary motion, the moment of inertia I of a point theoretically free of dimensions and that has a mass m at a distance r from the axis, the rotation shall be equal to:

$$I = m \times r^2$$

The formulas for the moments of inertia of bodies with different geometric shapes are described in the mechanic manuals.
Instead, the angular velocity ω is measured in radians per seconds (rad/sec).
1 rad = 57.3°, therefore:
90° correspond to 1.57 rad, 180° to 3.14 rad, 360° to 6.28 rad: The kinetic energy resulting from the rotation J is equal to:

$$J = \frac{I}{2}\omega^2$$

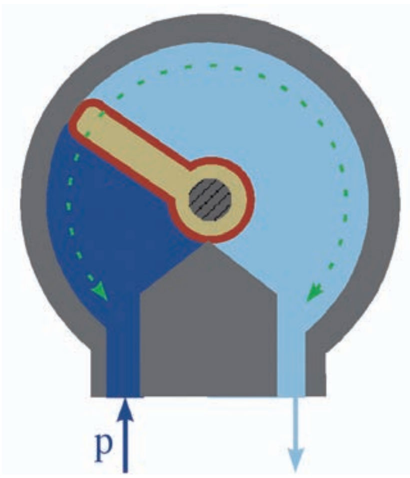
Each rotary actuator has its own absorbing capacity expressed in Joules, and according to this, we can calculate the rotating times of a determined mass fixed to an arm:

$$T = \sqrt{\frac{2\, I \times \upsilon^2}{E}}$$

T = rotating time in seconds
I = moment of inertia in N/m2
ϑ = rotation angle in radians
E = kinetic energy in Joules

The rotating time must be equal to or higher than the calculated value.
The pinion/rack system is mostly used, but there are other devices that use a rotor inserted in a cylindrical seat. The rotor is equipped with sealing gaskets in order to separate the two chambers. Regulating mechanical stops determine rotation angles.

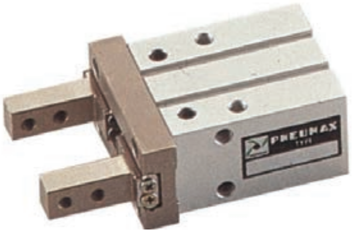
ROTARY VANE

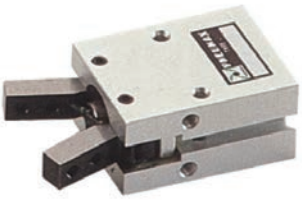


13.18 MANIPULATION, PLIERS OR CLAMP FINGERS, TRANSFER UNITS

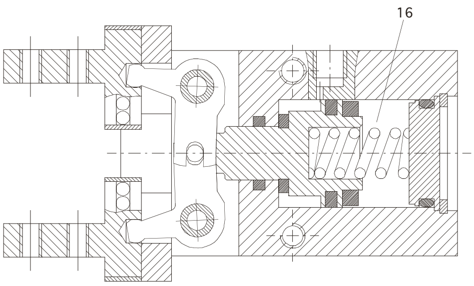
These actuators are manufactured for the automation sector that deals with robotics, manipulation, assembling etc.
They are specific equipment and the pneumatic cylinder that activates them allows closure or opening of the “prongs” that may catch different objects.
There are many versions of this equipment, and they may have different sizes with the purpose of serving the mentioned sectors as most completely as possible. Sizing of the clamp prongs is completely different from the other cylinders. The force of the expressed total catch is the arithmetic sum of the force of each prong, and it must have a value 10 or 20 times the weight of the object that it shall catch. The reason of a similar sizing is that, in the vast majority of cases, the pliers move on another actuator in order to transfer the part, and many times this movement is a quick rotation. The pliers, due to the centrifugal force or to the friction ratio of the material that constitutes the object, could release the piece during its operation.

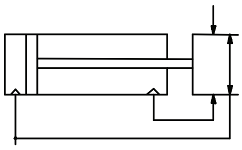
The prongs opening or closure may be a parallel or angular movement at 30° and 180°, or may have a self-centering function in case of three-pronged pliers.



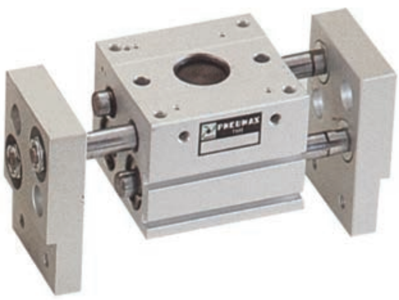



Each family of pliers offers different services, according to the diameter and length of the accessories mounted on the prongs.

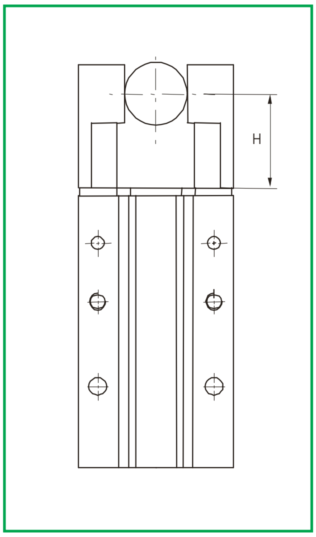




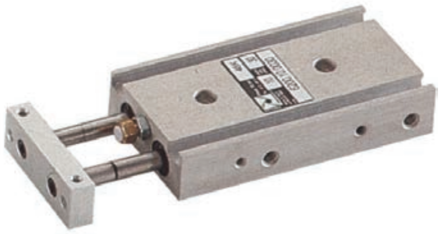
This section shows the linkage system adopted for parallel prong movements. Hands with a large opening stroke and whose prongs are synchronized by a pinion/rack system are used to handle large sized parts. Three different strokes are planned for each of these hands.

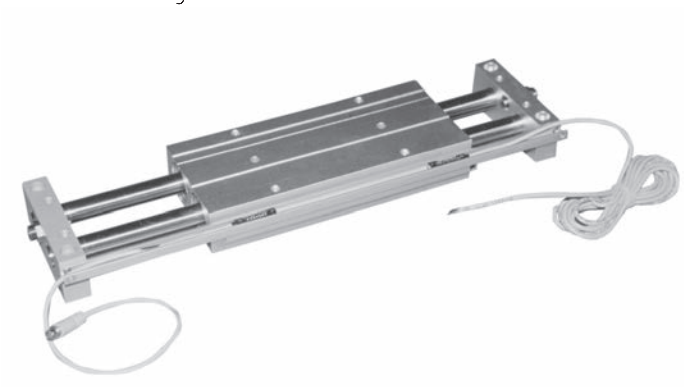


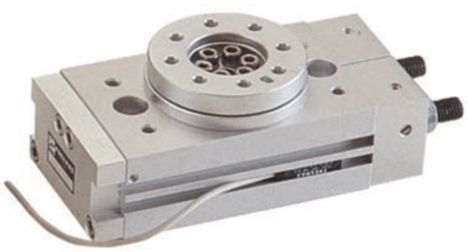
For each plier, the total catching force decreases when the dimension H increases. The data sheets display the ratio between force and dimension H.



The handling program is completed by the linear transfer units and by dedicated rotary actuators, on which the clamp's prongs are often mounted in order to constitute real manipulators.
Semi-slides, slides and guided compact cylinders are the transfer units, while the single and double rack rotary actuators are the rotary units.



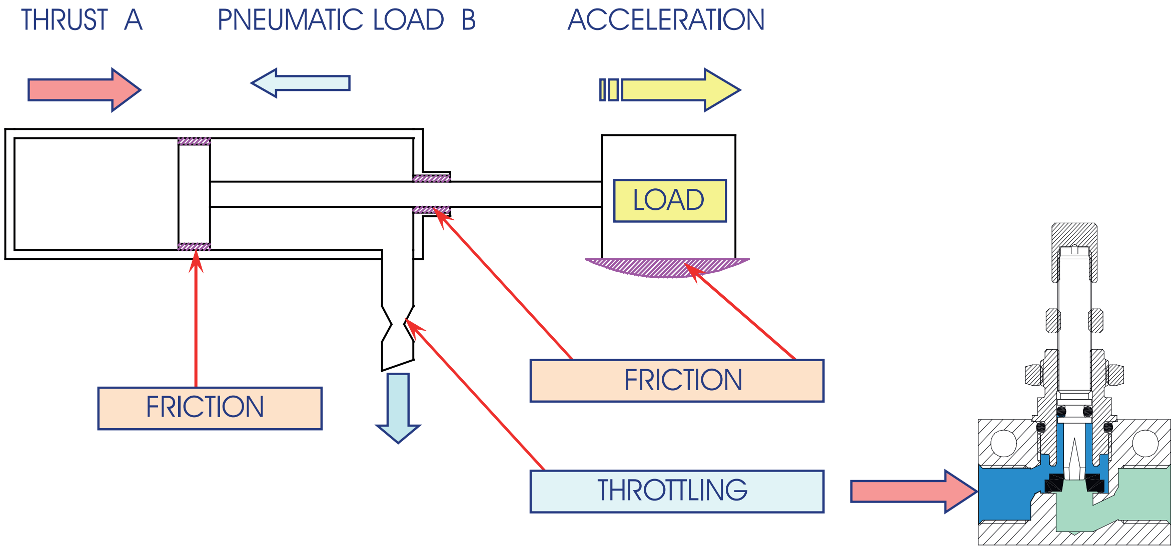




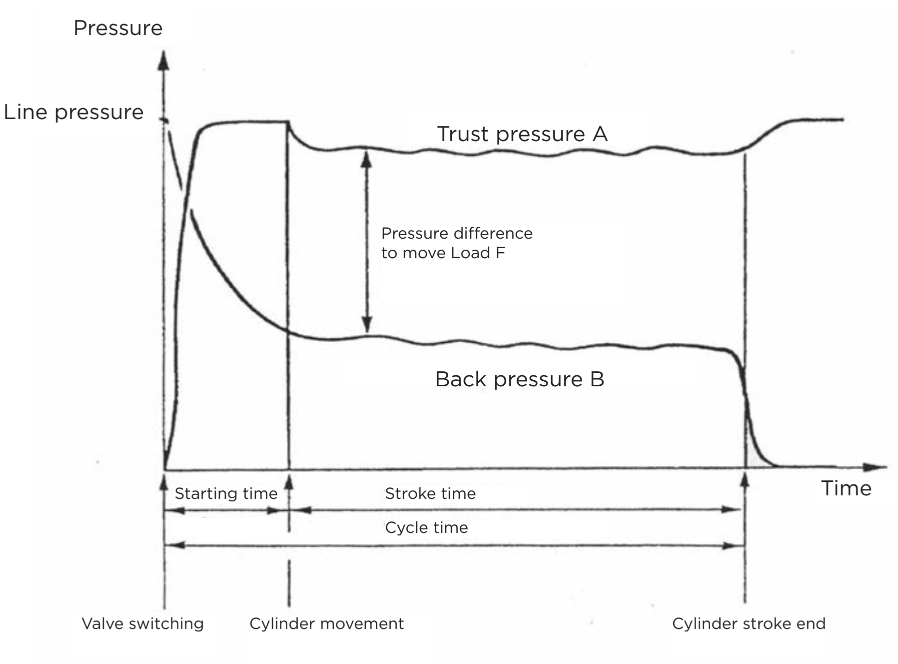
The linear units may be sized as the cylinder as well as the rotating units follow the sizing criteria for rotary actuators.

13.19 SPEED CONTROL

For all the types of actuators found until now, their working speed is carried out by restricting the air in the unloaded chamber, except for certain particular cases.
Air being a compressible gas, it is difficult to control the speed, especially at low speeds. Obtaining constant speeds is impossible because any variations due to resisting loads, sudden temperature or pressure changes are translated into variables that influence the speed. To simplify, we shall illustrate the speed controlling system schematically.



When the back chamber is fed, the front chamber is set to unload, and a variable throttle that controls the flow rate in the direction of the arrow is interposed between the discharge of the control valve and the cylinder. The diagram described in the following page shows what happens if we consider the pressures that are produced within the two chambers.
The motion or thrust pressure A waits for the counter unloading pressure B to reach a value such that causes the difference between A and B to express a force that is able to overcome the resisting loads and frictions, and then to imprint its acceleration. When we regulate the throttle, we are increasing or decreasing the counter unloading pressure B. The result is that a pneumatic load shall insist in a different way on the piston's front surface, causing speed regulation. The cylinder must be sized correctly respecting the load ratio. A too high load ratio does not allow good speed control. The difference between A and B should be already at the beginning very wide, and any constriction to unloading should cause its decrease, in such a way that the movement should be stopped due to the lack of the force needed to overcome the resisting force. The stoppage shall last long enough as to obtain the correct difference between A and B, and then the phenomenon is repeated accordingly. The result is the typical skipping advance, especially at low speeds.



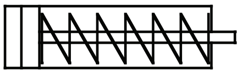
Even with correct load ratios, it is worth remembering that very low speeds may be not obtained by simple unloading control. The result shall be a skipping advance. We will now see how to act when an extremely low and constant speed control is required.

Mechanical rod stop

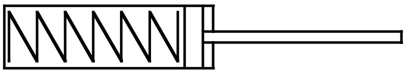
The pneumatic cylinder does not adapt well to uses where intermediate stops are planned.
The stops may be carried out trying to trap the working and unloading pressures in the two chambers, and waiting for the forces that stop the piston to be balanced.
This operation may be simple, but the stop point is absolutely not repeatable, and stability at this point is uncertain.
The situation may be improved using an accessory to be mounted on the front part of the cylinder that allows mechanical stopping of the rod. In this case, it is necessary to balance the chambers intercepting the inlet and discharge ways, or better still, powering both cylinder chambers playing with the pressures in order to reach stability.
After this operation, the rod stopping mechanism may act which has the task of maintaining the only load applied to the cylinder. The load is stopped in both directions by a double jaw mechanism. The stop is carried out in a negative way, meaning that the mechanism acts by sending a pneumatic control signal to the discharge and a spring activates the blocking jaws.
It must not be considered to be a safety device, but as a component that may be inserted into a system that is to be homologated.

The tightening force depends on the device's size to be mounted on ISO 6432 micro-cylinders starting from Ø 20 and on ISO 15555 cylinders from Ø 32 to Ø 125. We must always use rods with hard surfaces (chrome coating) and in those cases where stainless steels are necessary, we must mount stainless chromate rods.

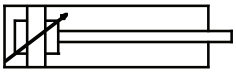
SUMMERY OF SYMBOLS



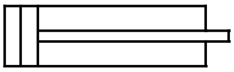
Front spring cylinder.



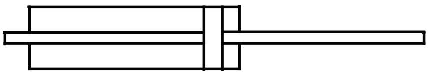
Rear spring cylinder.



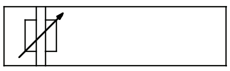
Double acting cylinder c/w cushioning



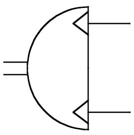
Double acting cylinder



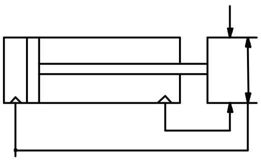
Double acting Twin rod cylinder



Rodless cylinder



Rotary actuator



Double acting pliers

Chapter 14

DIRECTIONAL CONTROL VALVES

14.1 DIRECTIONAL CONTROL VALVES

Directional control valves deflect compressed air flow along the internal workings by means of external activations of controls.
These valves are characterized by:

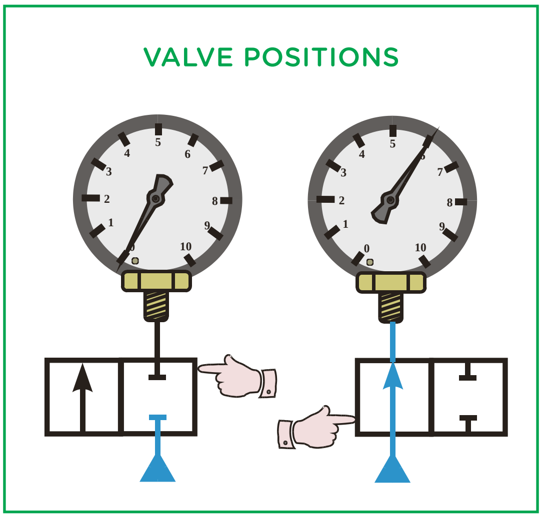
- **Number of ways**
- **Number of positions**
- **Type of activations**

Number of ways and positions

The number of way of a valve may be identified very simply by counting the number of joints in its body, excluding those dedicated to controls.
If a valve has two joints in its body, we can define it as a two-way valve, if it has three, it is a three-way valve, etc.
The number of positions results from the positions that the valve may assume when it is activated by the controls, including the resting position. In common practice, a 2/2 valve defines an equipment that possesses two ways and two positions. The first number identifies the number of ways and the second one after the slash, the number of positions.

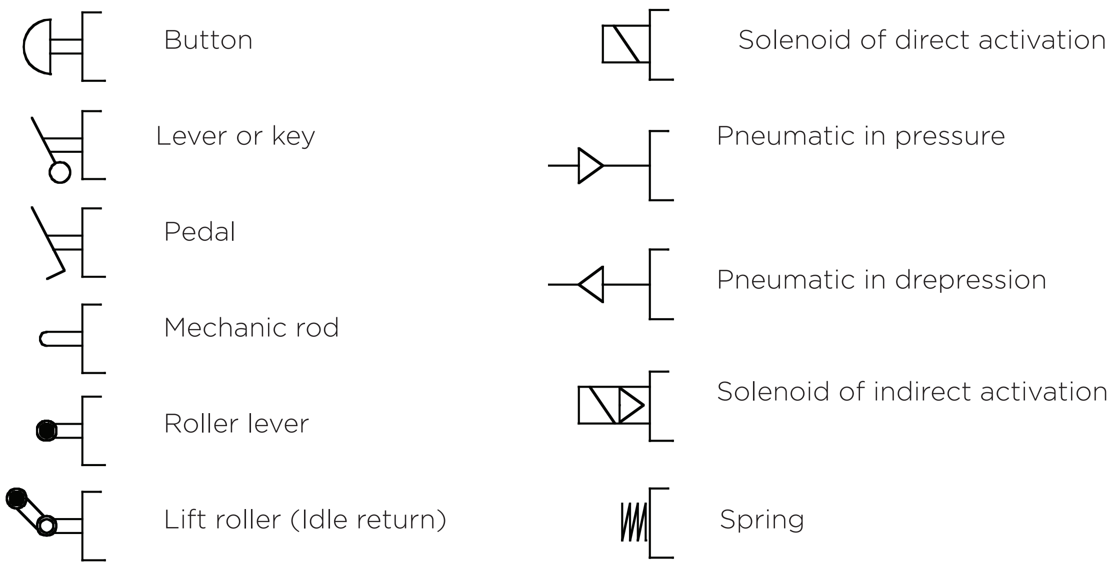
For 2/2 and 3/2 valves, identifying the function of the rest position is important, in order to know if the compressed air is intercepted at the powering port, and if it allows its outlet only in the presence of a control signal, or if it is free to flow to the outlet and if it is annulled by the control signal.
In the first case, we define it to be normally closed (N.C.) and in the second case, normally open (N.O.). The symbols that identify the valves are created in order to describe their operation, the number of ways, positions and activation type. Each square represented in the symbol corresponds to a position, and their function is defined graphically inside of each.

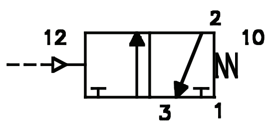
The symbol described above depicts a 2/2 N.C. valve assuming the right square as the rest position. Later, the type of control and the numbers that identify all the joints shall be added in order to complete the symbol.
In the symbol, the valve always assumes the position adjoining to the received order.



Standards establish that the powering way is to be identified by the number 1 and that it is always marked in the square that defines the resting position. The outlet way in cases 2/2 and 3/2 is always defined by the number 2 in the same square.
The control joints have the numbers 10 and 12.
10 is the control adjoining to the resting position and 12 is the one adjoining to the second position.

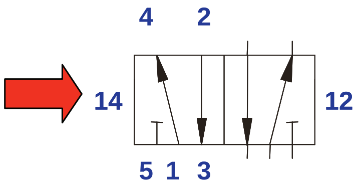
The symbol drawn above represents a 3/2 N.C. valve and, as we can see, its discharge way has the number 3, and in the rest conditions outlet 2 is not intercepted, as is the case of 2/2, but it is connected to discharge 3. The arrow indicates flow direction. We can notice how the identifying numbers increase progressively when the number of ways increases, while those of control remain unchanged.
The number of the control signals has specific meanings.
A 10 indicates that inlet 1 is connected to nothing; while a 12 means that 1 must be connected with 2. When 12 intervenes, the square to be considered is the one adjoining (left figure at the bottom on the previous page), 1 is connected with 2, and 3, that was connected before with the discharge is now intercepted.
The valves with repositioning on 10, by means of a spring, are called **monostable** or **unistable** valves because the resting position is predefined. It also means that the outlet signal shall have duration equal to the control signal. Disappearance of the control signal shall change the status of the outlet signal.
A valve that has no preferential position remains in one of the two positions until one of the two signals is selected. The control, in this case, may be an impulse, and it shall switch the valve under the condition that the opposite control is absent. They are valves defined as **bistable** or **memory** valves, because they remember the last control signal received.
The completion of the symbol requires the control graphic related with numbers 10 and 12. The most common symbols used are:

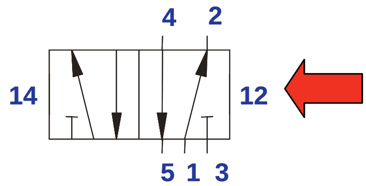




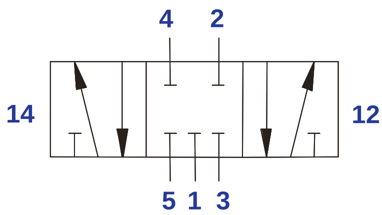
As an example, a 3/2 N.C. valve with pneumatic control and spring return is described. The 2/2 valves are used in the N.C. and N.O. versions as simple shut-off valves, while the 3/2 valves are used to control single-acting cylinders or to send signals to other valves by virtue of the third discharge way.

Instead, two outlets that complement each other and that feed the two chambers alternatively are necessary in order to activate a double-acting cylinder.
A suitable valve is provided with 5 ways, two of them are outlets, one is the main air and the remaining two are the exhausts dedicated to each of the two exits.

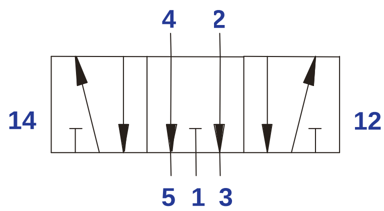




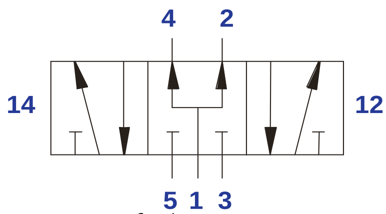
In this case, the control number 10 disappears and is substituted by number 12, which now determines the resting position (1 connected to 2). The number 14, meaning the connection between 1 and 4 is inserted. 4 is the complementary exit way to 2 and is connected to its respective exhaust 5. When 14 acts, the square to be considered active is the adjoining one. Completion of the symbol is made combining the control symbol with the body symbol, thus obtaining the respective complete 5/2 symbol.
Employment of three-position valves is common. In these cases, the symbol is made of three squares, and the resting position is the central one. Usually, these are five-way valves and the central position must have a specific function as "closed centers", "opened centers" and "fed centers".



closed centers



opened centers



fed centers

The central position is kept mechanically by stops or calibrated springs at the two control sides, and the working lateral positions are obtained sending the controls to 12 and 14. These valves, except for particular cases, are unstable.

Summery of the junctions' numbers

PNEUMATICS						3 WAY		5 WAY	
ISO	1	2	3	4	5	12	10	14	12
CETOP	P	B	S	A	R	Z	Y	Z	Y

After having analyzed the functions of the valves by means of their symbols, let us see their operation by means of simplified sections. These sections introduce us to the manufacturing classification of valves.

14.2 MANUFACTURING METHODS

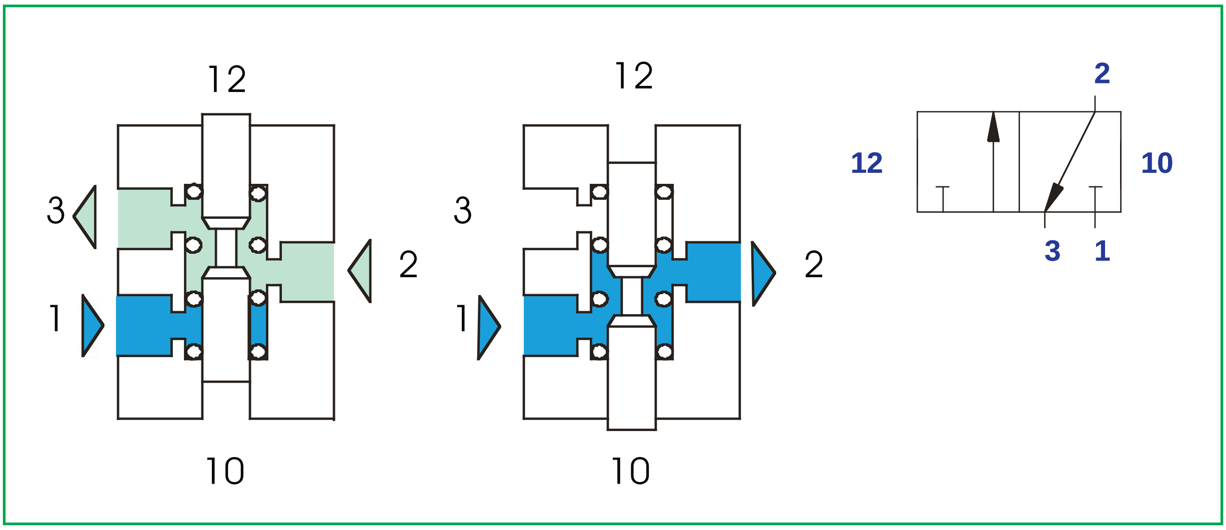
The symbol, which is stamped on the body of the valve, provides us with specific indications regarding its operation, but does not define its size or how it has been manufactured. The methods used to manufacture a valve are several, but only two of them are mainly used today.

- **Spool or drawer valve manufacturing**
- **Shutter valve manufacturing**

Spool or drawer valve manufacturing

This type of valve uses a shaft, suitably molded, that slides inside the body of a valve equipped with gaskets, kept in its housing by means of spacers. The threaded junctions of its respective ways are located on the lateral side of the body.

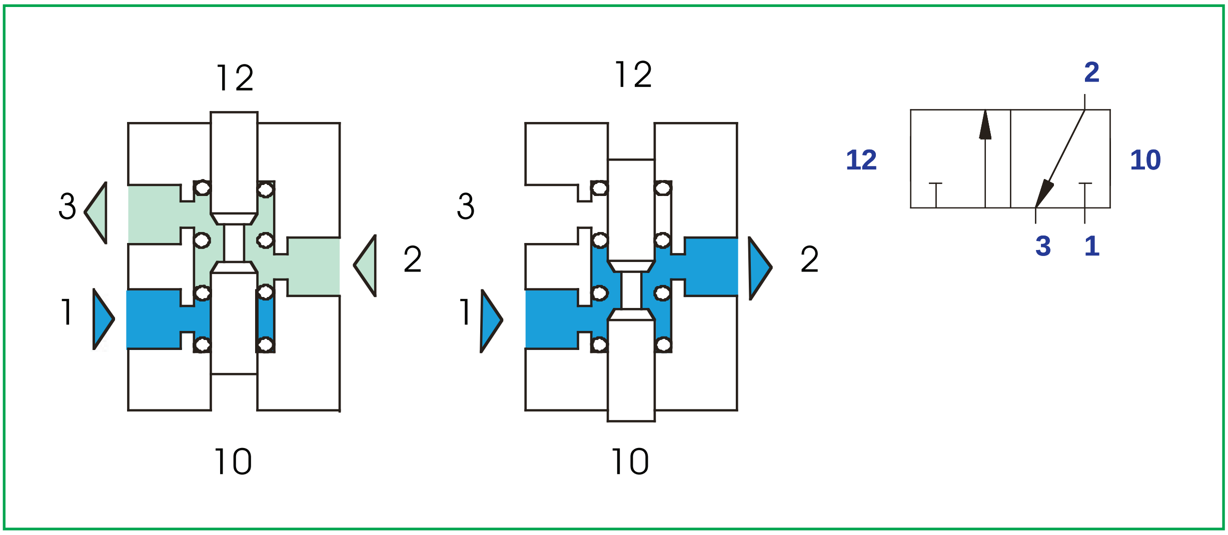
3/2 N.C.



The represented valve, and its symbol placed besides it, helps us to understand its operation.
The left figure shows the valve in a resting position with control 10 prevailing, while the right figure shows it while being activated with prevalence of signal 12. In addition, we can notice that the pressure acts always in perpendicularly to the spool and this way, the

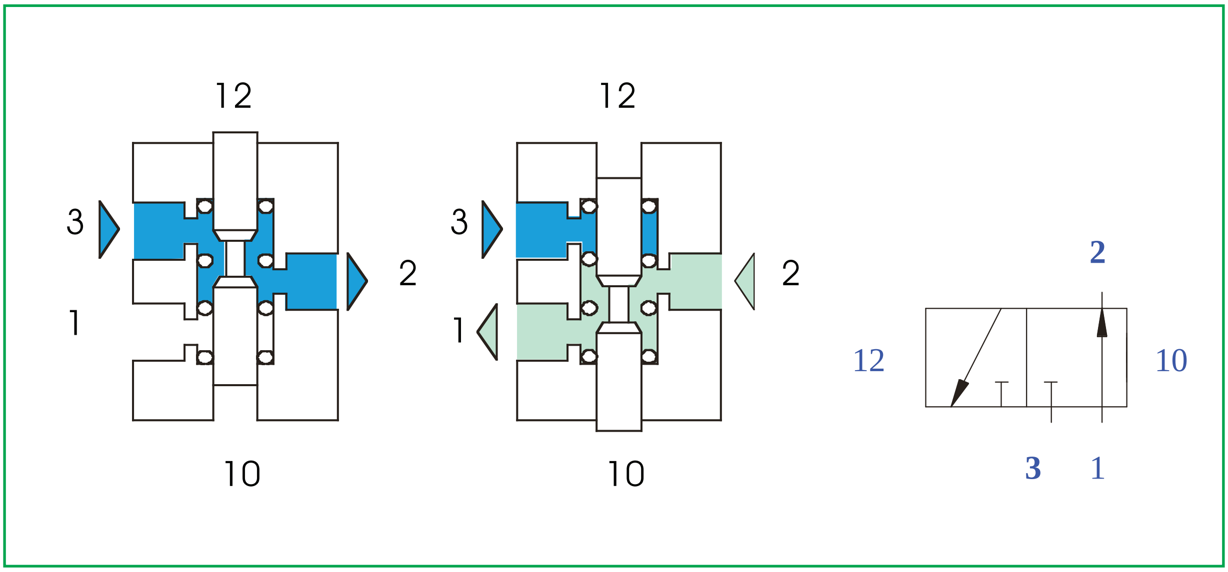
activating forces needed to commute the valve are always the same independently from the operating pressure. For this reason, they are called balanced spool valves.

3/2 N.O.



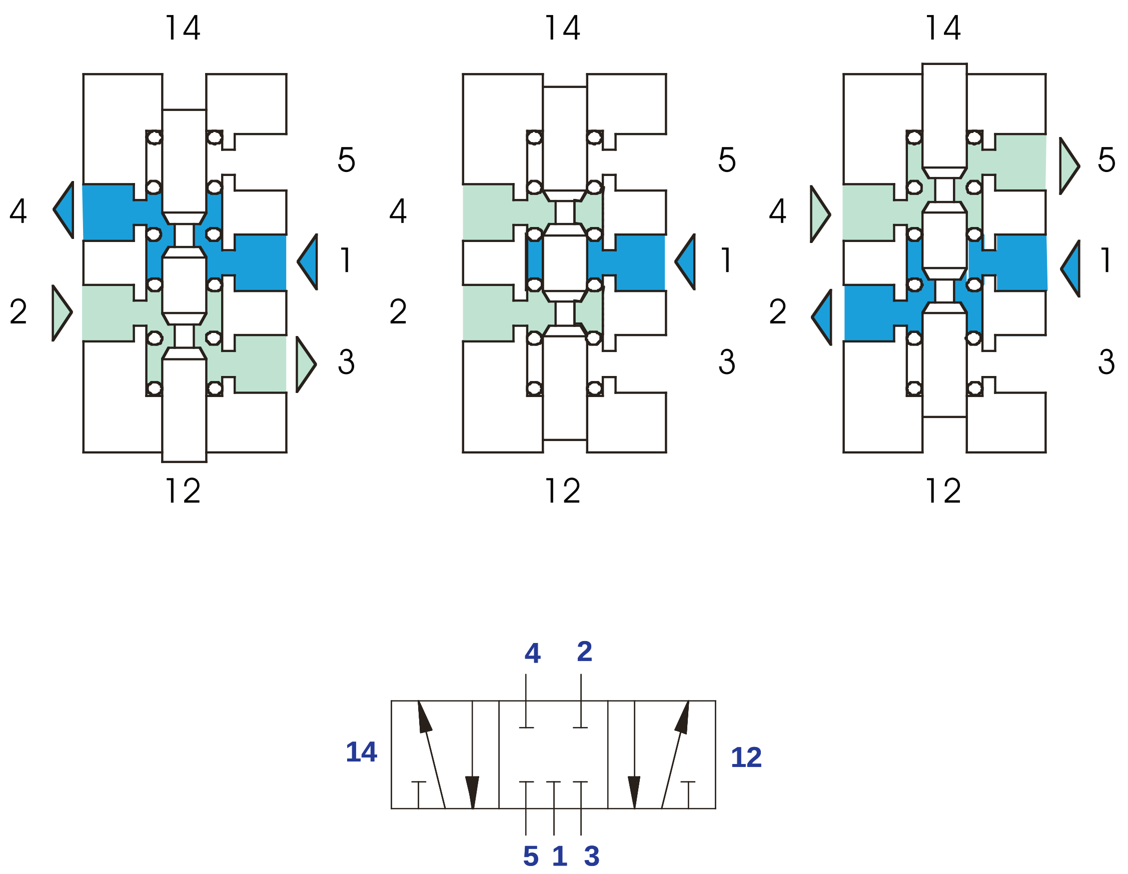
In the case of balanced spool valves it is possible to transform them from normally closed to normally opened by simply reversing both the feeder and the exhaust, and it is also possible to transform it into 2/2 by closing exhaust 3 with a plug.

5/2



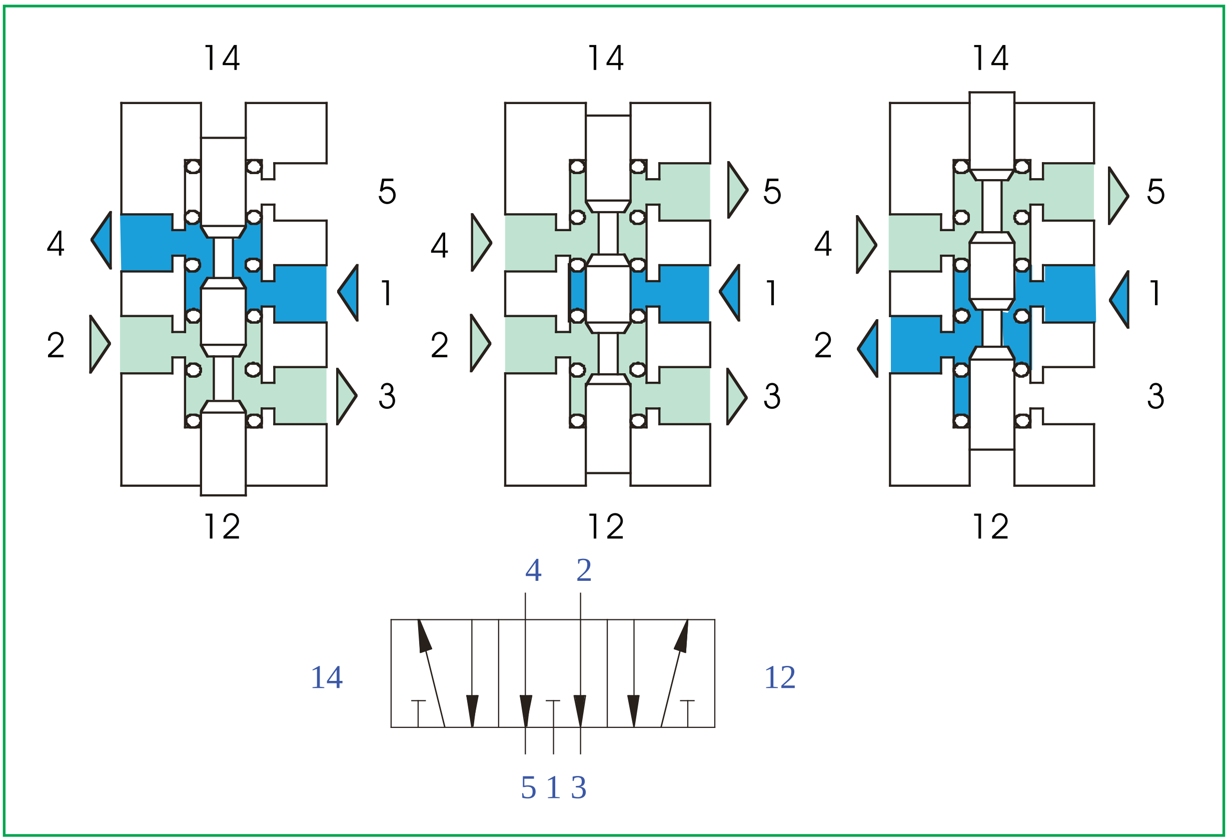
Also in this case, the left figure shows the valve in its rest position and the right figure shows it in its working position. We can see the separated exhausts for each outlet, with exhaust 3 dedicated to outlet 2 and exhaust 5 dedicated to outlet 4.
When discharge 2 is under pressure, outlet 5 is in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

5/3 closed centers



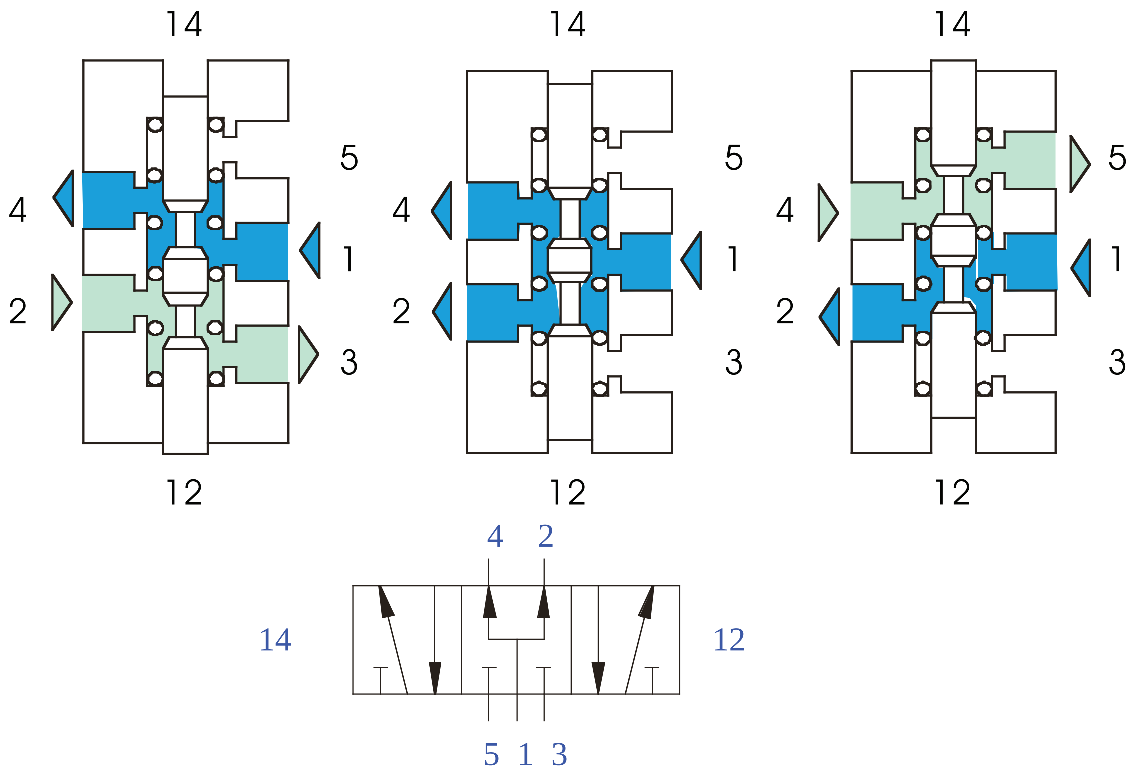
The right and left sections show the valve activated by 12 and 14 and, as we can see, it acts as a normal five-way valve.
In absence of controls, the valve assumes the central position and intercepts all the passages. In case it is used to control a double-action cylinder, blocking discharges 2 and 4 means to trap the pressure that at that moment is in the two cylinder chambers. The cylinder shall keep its own stroke going until the forces acting on the two sides of the piston reach their equilibrium.
At this point, the cylinder rod stops.
Therefore, this is a valve used to perform intermediate stops, but that has no possibility of repeating the same position twice and, in case of leakages from the joints/ pressure necks, the stop would be precarious because the counterbalanced forces are now balanced.
As already mentioned, it may be used with rod stopping mechanisms.

5/3 exhaust or opened centers

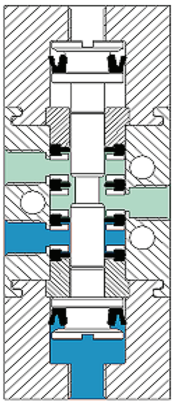


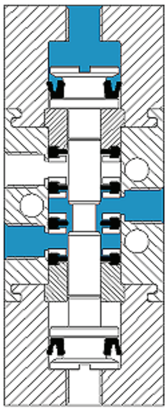
The difference with the previous valve lies in its central position. In this case, feeding is intercepted and discharges 2 and 4 are at the exhaust by means of 3 and 5. Controlled actuator chambers operate at atmospheric pressure. A cylinder may be moved manually freely along the entire stroke. One of its uses may be represented by the control of a pneumatic motor, with clockwise or counterclockwise rotation according to controls 12 and 14, where the central position determines their stopping position.

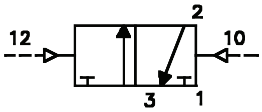
5/3 powered or under pressure centers



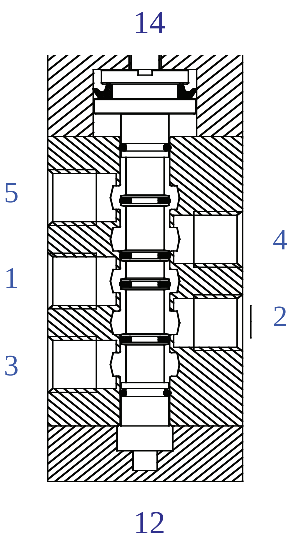
The central position feeds the two cylinder chambers and intercepts both exhausts. It is very useful in applications with the mechanical rod stopping since it compensates eventual leakages from the pressure necks. But the condition is that the piston surfaces are to be identical. Therefore, it must be employed with cylinders with hollow through piston rod. The valves introduced are the most commonly used in the compressed air automation scene.
The balanced spool version is simple, reliable and easily manufactured. In case of three-position valve, we can see that by simply substituting the spool, the three versions just mentioned may be manufactured. But all of them must perform relatively large working strokes in order to open passage spans that may supply flow rates consistent with their valve size. They may operate with or without lubrication supply according to the manufacturer's instructions.

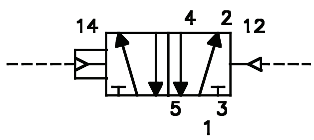






The valve described in this section is a traditional 3/2 N.C.one with pneumatic activation and pneumatic return at the resting position (left) and at the working position (right) with their respective symbol. It is manufactured, as previously said, by inserting in its body gaskets and spacers, inside a molded slider spool. The gaskets are fixed inside the body, so they may be defined to be passive. A similar solution is quite bulky and the courses that the air is forced to follow are quite tortuous. The flow rates are not optimal when compared to their valve size. The valves of the next generations have been designed in order to optimize the flow rate to its maximum. Currently, it is increasingly important to reduce their sizes and weights, trying to improve the equipment's performance as well as to extend its lifetime. Therefore, valves that carry sealing gaskets on the spool are created, and their spacers and fixed gaskets disappear with remarkable passage span streamlining. These flow rates increase remarkably with the same sizes.
The gaskets move with the spool and we can define them as being active.
The following image shows the section of a valve 5/2 with pneumatic activation and differential internal pneumatic return, which operates as a real spring.

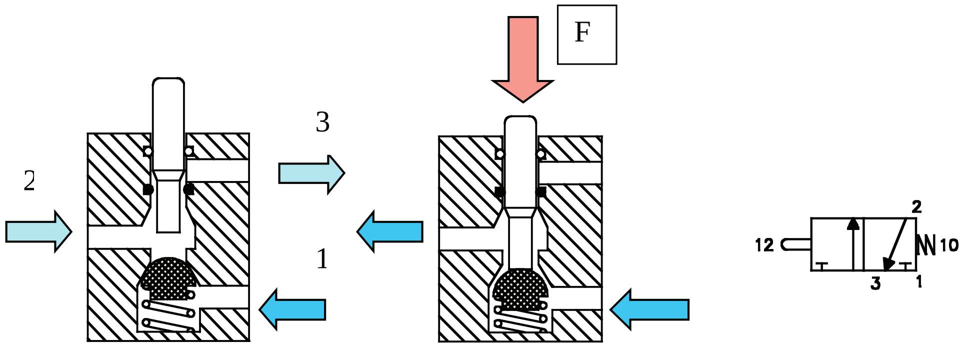




The pneumatic control 14 area is wider than the 12 area and therefore 14 prevails over 12. The supply of compressed air toward 12 is carried out directly by the main feeder 1 with a small channel located inside the body.

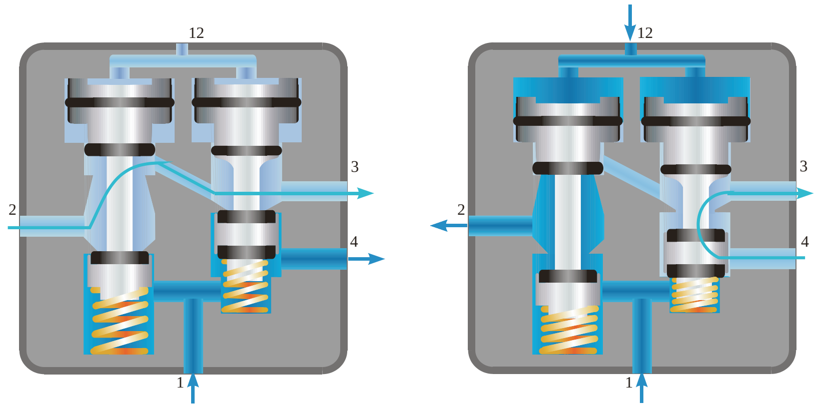
Shutter valve manufacture

The shutter valve manufacture is portrayed by a frontal sealing without crawling bodies. The sealing system is made by a disc equipped with gaskets that detach axially from a valve seat. This way, the valve's conduits are connected. A perfect sealing and large flow rates are also obtained with short excursions of the sealing body. The activating forces are weak when the valve is not fed, but when supplied with compressed air, this force increases when pressure increases. Graphic symbols do not distinguish the type of manufacture; therefore they are the same as the spool valves.
The sketch shows a shutter valve's operating principle.

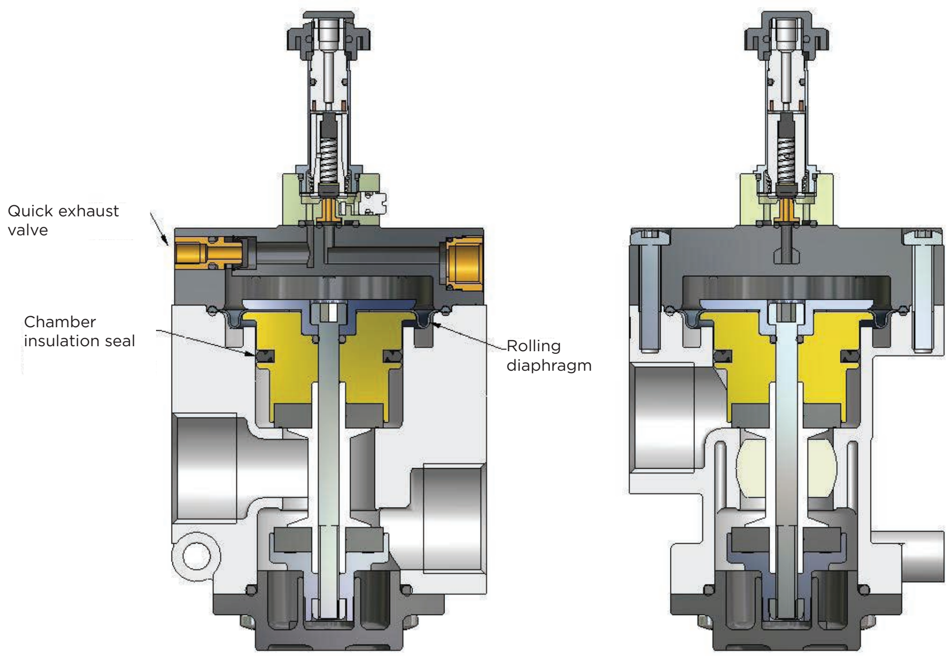


The operating pressure acts on the shutter's lower part and logically, the actuating force F must increase when the operating pressure increases. It carries out very quick commutations, since the opening strokes are very short, and they may operate without any lubrication because they have no crawling bodies. They are often used whenever high flow rates are needed. They are not suitable to be manufactured in the four-way version. As we can see in the following figure, their assembly is definitively difficult.

SERVO-DRIVEN SHUTTER VALVE 4/2



In case of 4/2 valves, the exhaust of outlets 2 and 4 is always shared with 3.
The assembly is the exact composition of two 3/2 N.C. valves (left side of the valve in the two figures), with a 3/2 N.O. valve on the right side with common feeding.



14.3 VALVE CONTROLS

The valves are activated by means of controls that may be of different types:

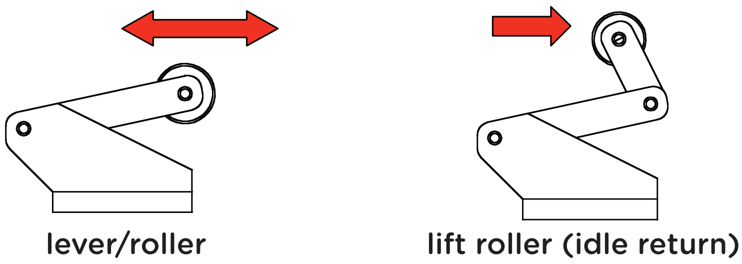
- **Manual**
- **Mechanical**
- **Pneumatic**
- **Electric**

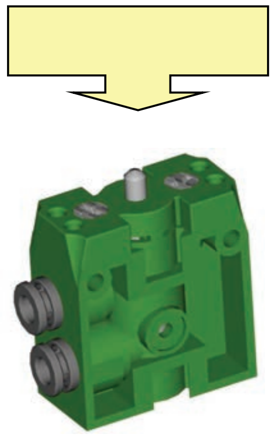
Manual activation

Manual activation is obtained by mounting a manually activated operating element on the valve body. They are almost always positioned on the unit's control panels and they may be monostable or bistable. The bistable function is obtained by a mechanical retainer inside the operator. Usually, the size of these valves is small because they are only intended to send control signals toward other distributors, and therefore do not need high flow rates. Very rarely they have greater sizes suitable for direct control of a cylinder. The operating element calculates the use of all the types of valves considered till now.

Mechanical activation

Mechanical activations have been created in order to detect the position of mechanical parts of a moving machine, and to send pressure signals in order to control the working cycle. They may be activated directly even from cylinders whose rod is equipped with a cam, with the purpose of signaling the performed stroke.
The most common valves are those with the lever/roller or the lift roller. The lever/roller releases the signal when it is activated in both directions, and therefore, it is used as a stroke limit detector, while the lift roller may be activated only in one direction. In the opposite direction, the roller is pressed without activating the valve. Therefore, it may detect the passage of the cylinder rod in the desired direction and be placed at any point of the stroke.





Pneumatic activation

Pneumatic control is always performed remotely (remote control) and is used to perform an exaggeration of the flow rate.
A pneumatic signal, released by a button or by a small stroke limit valve that has a very poor flow rate, drives another greater valve with wider flow rate.

Electric activation

The kind of activation mostly used in pneumatic automation, and consists substantially in transduction of an electric signal into a pneumatic signal.
The section referred to electro valves shall explain how this is carried out.

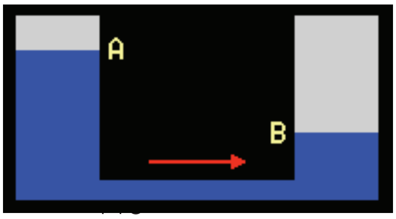
14.4 ELECTRO VALVES

Electro-valves transform an electric signal into a pneumatic signal. They are popular devices, and are used whenever the organizing criterion for automatic equipment establishes electric signals as exits, as in electronic control systems, for example.

We should recap the basic electric principles before entering into the subject of electro valves.

Voltage

A simple example may explain the meaning of voltage:
Two water tanks are connected by means of a tube. If level A, in the first tank, is identical to level B of the second tank, no movement of the water is observed, while if there is a difference in height, some water should pass from the tank with the higher level to the tank with lower level.
A difference in levels is necessary to obtain this flow. Therefore, voltage is the potential difference between the two poles of a conductor and is measured in V (Volts).



Current

Current is an electric charge flow that crosses a conductor and in pneumatics is comparable to the flow rate of the air in a tube. The larger the tube is the higher shall be its air capacity. An identical situation shall occur in the conductor.
The measuring unit for current intensities is the A (Ampere).

Power

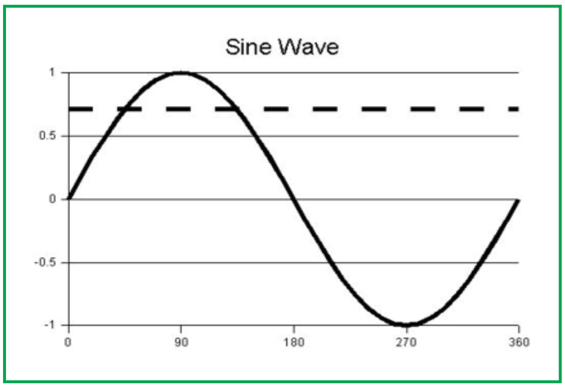
The power is the product of voltage by current:

$$P = U \times I$$

The power measuring unit is the W (Watt).

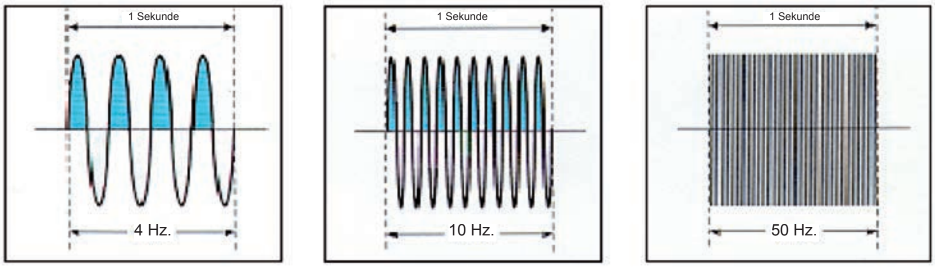
Alternating current

Alternating current is featured by a current flow that may vary along time in both intensity and direction, with more or less regular intervals. Fluctuation of the electric voltage value along time is the waveform.
Commonly distributed electric power has a sinusoidal waveform, and the value measured in V is not the highest peak of the wave, but is a lower value, marked with the dotted line in the diagram, that is defined as Mean Root Square voltage (Veff).



Frequency

Frequency is the number of forward and backward cycles performed during one second. Frequency is measured in Hz (Hertz). In Europe, alternating current has a 50 Hz frequency, and in America it is equal to 60 Hz.



Direct current

The direct current is portrayed by a current flow that is constant along time in both intensity and direction. In direct current, contrary to alternating current, respecting the current direction, or rather its polarity is very important.

Resistance

A conductor, according to its materials, opposes the current's passage offering a resistance. A short cable with a large diameter has a lower resistance than a long and thin cable made with the same material. The comparison with pneumatic tubes is correct, even if in pneumatics no unit exists for measuring resistance, but exists for its opposite, which is conductivity. Its flow capacity is measured with the equivalent section in mm2 or with kv or Cv flow factors.
The electric resistance measuring unit is the Ohm. Resistance is also an electronic component that acts like a break.

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

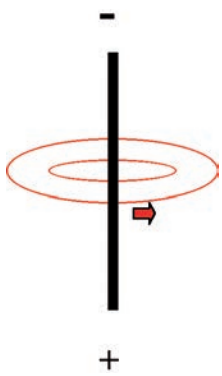
R = Resistance expressed in Ohms
I = Current intensity expressed in Amperes
V = Voltage expressed in Volts
W = Power expressed in Watts

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.

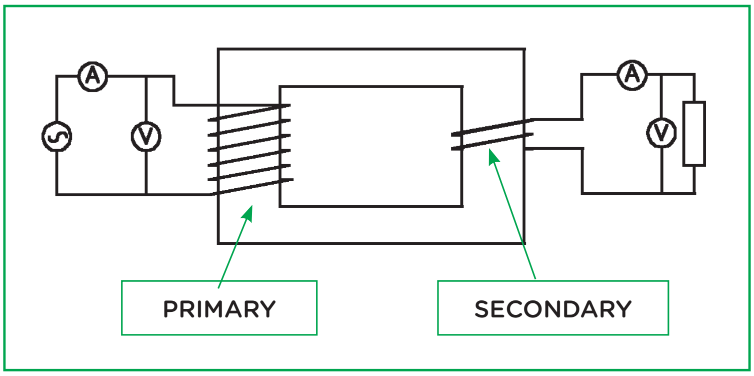


Induction

Transformer principles If a cable is moved across this magnetic field, an electric current is produced within it. This electric current is called electromagnetic induction. This phenomenon is used in dynamos and generators, where the current is induced to a coil that rotates within a static magnetic field. Both direct and alternating currents may be produced.

Transformer principles

A transformer is made by two or more coils commonly wrapped around an iron nucleus, as shown in the following figure. According to the principle of action and reaction, an alternating current produces an alternating magnetic field, as well as an alternating magnetic field produces an alternating current in a coil that is located inside the field. If the primary envelopment has an amount of loops greater than the secondary one, feeding in an alternating current produces a high voltage with a low current. In the secondary wrapping, having a smaller amount of loops, we shall have low voltages and high currents.



The current with its respective magnetic flow produced in the secondary winding shall have a lag with respect to the primary one.
It is possible to produce high voltages and low currents or vice versa.

Phase shift

The inductive resistance is the cause of the phase shift, and in case of pure inductive resistances, the phase shift shall be equal to 90°, as occurs in the case that the secondary wrap has only one knuckled loop, that therefore has no Ohm's resistance (short circuit loop).
With the Ohm's component of the coil, this phase shift is lower than 90°. For example, in alternating current motors, the indication cos φ is always to be found, where φ represents the angle of this phase shift. Therefore, the effective average power is:

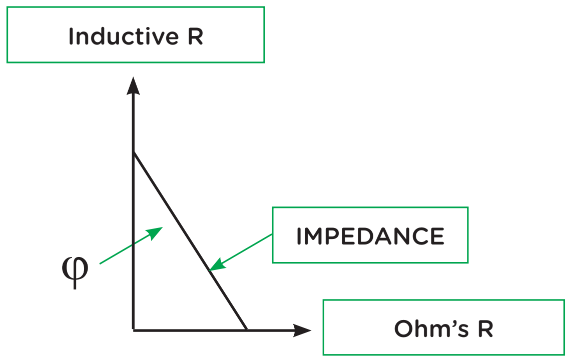
$$P = Veff \times Ieff \times \cos \varphi$$

where Veff is the effective voltage and Ieff the effective current (1/ 2 = 0.707 of the peak value). This effective or real power is measured in Watts, contrary to the apparent power that is measured in VA (Volts Amperes).

Impedance

Impedance Z is the resultant of the Ohm's resistance of the wire and its inductive resistance.

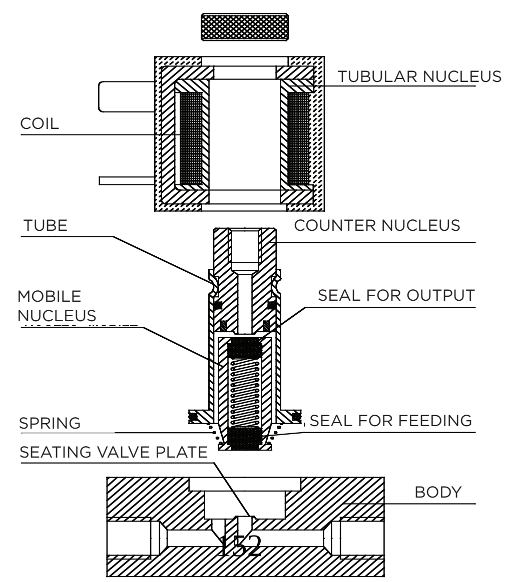
$$Z = \sqrt{R\,ohm.^2 + R\,ind.^2}$$



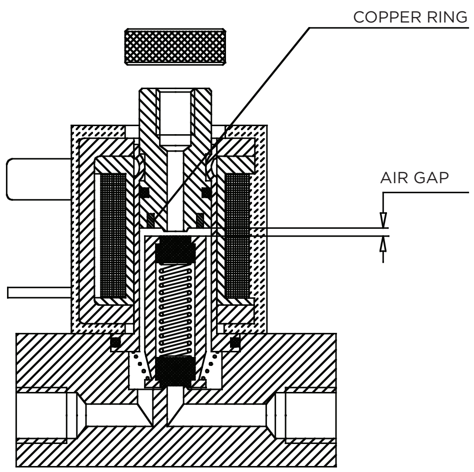
Therefore, impedance is simply the total resistance, and depends on the phase shift angle and is measured in Ohms.

Solenoids

At this point, speaking of solenoids, we can introduce the subject of electro valves.



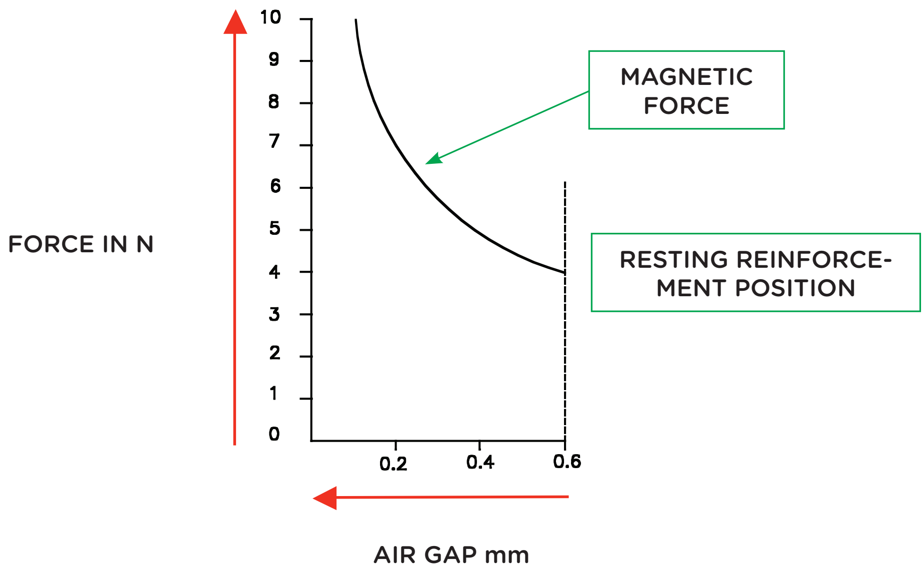
A conducting wire wound around a non-magnetic tubular nucleus, after being fed, concentrates the power lines of its own magnetic field along the central axis of the winding.
The point where the power lines enter and exit from the coil are called poles, just as magnets. If an iron nucleus is inserted inside the non-magnetic tube, the magnetic flow increases notably, because the power lines pass at least a thousand times easier across the iron than across the air.
The electro valve's operating principle is like the one of the lift solenoid, made by both a fixed and a mobile reinforcement and by a coil.
As we can see in the figure, inside a non-magnetic tube, the fixed reinforcement is anchored (counter nucleus) and the mobile one is inserted (nucleus), fastened by a spring.
The assembled tube is inserted into the coil's tubular nucleus.
The mobile reinforcement is pulled toward the fixed part by the attraction force produced by the flow when the coil is excited. This allows opening and closing the air transition seating alternatively thanks to a gasket mounted on the mobile nucleus, as the figure shows.



Magnetic forces depend mainly on their air gap, or rather on the distance existing between the fixed and mobile reinforcements.
The diagram described in the following page illustrates this concept. In the resting position, the force is equal to about 4 N, in the mid of the stroke it has reached 6 N, and at its end it has reached 10 N. This means that the speed increases remarkably during the stroke. We must consider two facts for alternating current solenoids:

- Induction changes with the mobile reinforcement's position
- Current, together with magnetic forces, drops down to zero two times for each period.

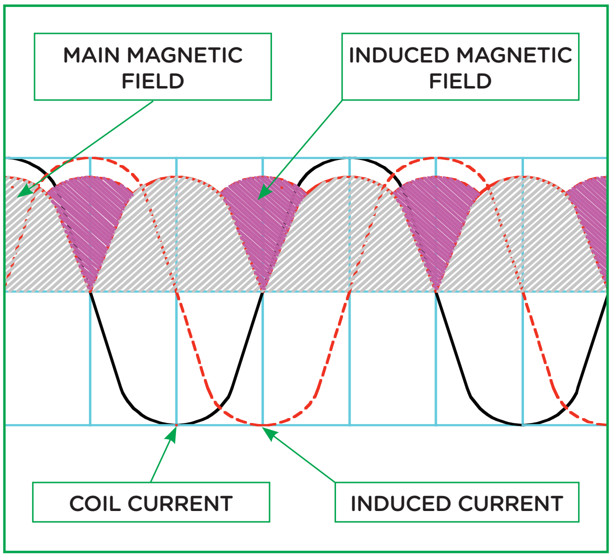
Initially, with maximum air gap, the force and the inductive resistance are very low. This means that a strong intensity current is passing through the coil.



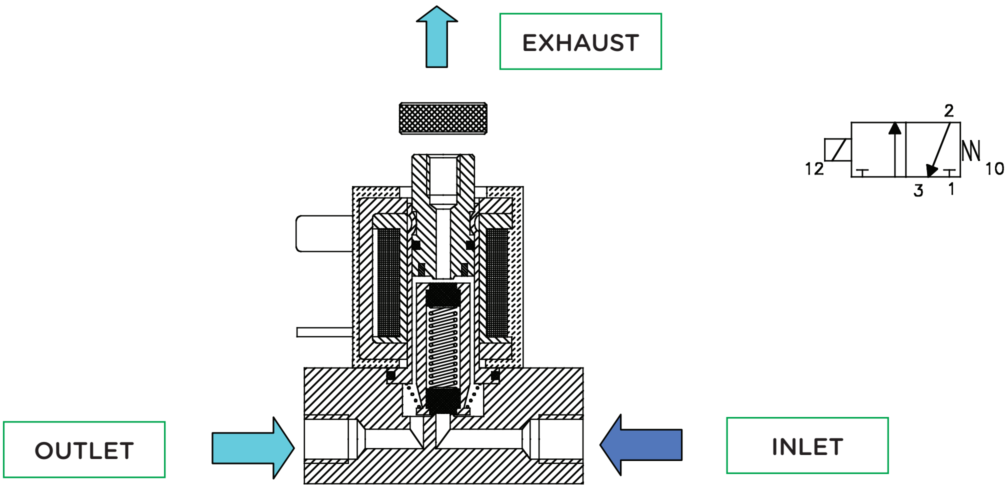
For this reason, the reaction is more violent than in a direct current coil.
When the air gap is closed, the total resistance and induction increase, and consequently, the absorbed current decreases.
The holding current and power are lower than the breakaway starting current and power.
In case of direct current, the power remains constant because voltage and current values remain always the same.
When the reaction time of the direct current solenoid must be shortened, a higher voltage with duration of a few milliseconds may be applied. The resulting effect is very similar to the breakaway in alternating current. When the mobile nucleus reaches the end of its stroke, the holding may be carried out with a reduced voltage, up to the half of the rated voltage.

Loop phase shift

In fixed reinforcements, operating under alternating current conditions, the copper ring is present, as shown in the previous figure.
Every time that the current returns to zero, the mobile nucleus starts to come back under the spring's thrust. When the current increases again, it is attracted again. This creates the buzzing and a continuous slamming of the nucleus against the reinforcement, a hundred times per second, and causes quick deterioration.
The solution is to create a second magnetic field as out-of-phase as possible, toward 90°. The loop phase shift performs this task and the operating principle is the transformer principle.
The loop is knuckled, and is therefore in short circuit, and represents the secondary winding, while the primary one is constituted by the coil. The closed loop has an Ohm resistance equal to zero and, therefore, the phase shift shall be near 90°. Also, the voltage shall be near to zero while the current shall be very high. This current creates a second magnetic field lagged 90° with respect to the main magnetic field.



The figure shows the final result and, as we can see, the effect of the second magnetic field nullifies the pulsation.
Thus, the buzzing is removed.
A closed loop mechanical supply may function also in direct current, because the described phenomenon is not engaged, since the transformer works only with alternating current (commonly voltages used are 220-110-24 V 50/60 Hz). Multipolar and serial systems work only with 24 V direct current.

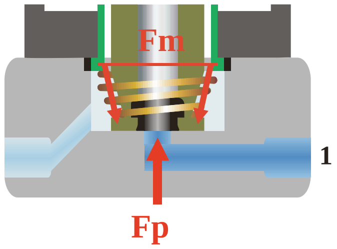


The figure shows a so called direct-acting electro valve. The air in fact transits directly across the mechanics of the assembly, from the entrance toward the outlet.
It is exactly a 3/2 N.C. shutter valve. Under the conditions described in the figure, the resting condition, the inlet air is intercepted and the outlet air is discharged by means of the fixed nucleus' central hole.

When the coil is excited, the mobile nucleus is sucked upward, closing the discharge way by means of the top rubber, and at the same time it clears the lower transit opening, allowing the air to flow toward the outlet.
These are devices suitable for poor flow rates for the reasons we will now proceed to explain. First at all, let's examine the forces that contrast each other in this type of system.

FORCES ACTING ON THE ELECTRO VALVE SHUTTER

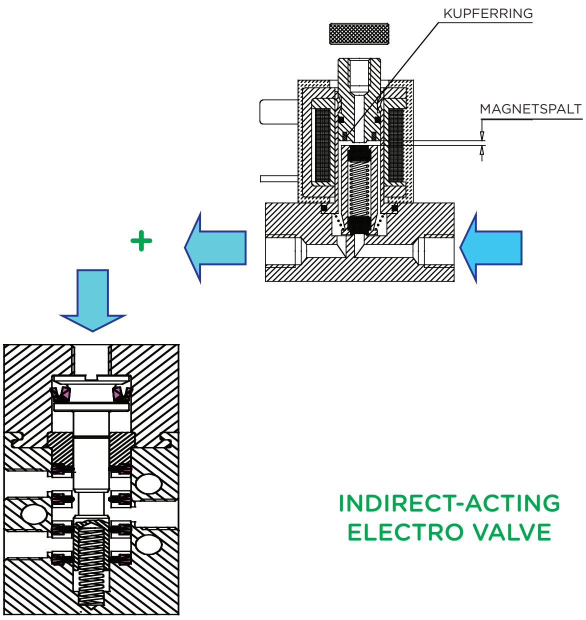
Balance condition
Fp = Fm



In resting position, they act:

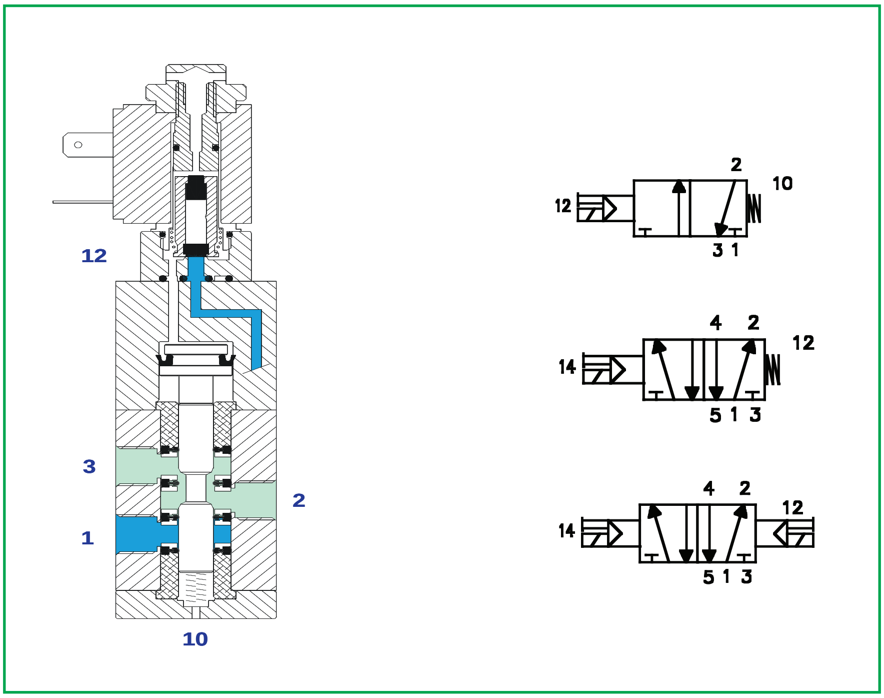
- Downward: force of the spring and weight of the mobile nucleus
- Upward: force of the pressure for the exposed section's surface.

The forces that act downward must be overcome by the magnetic force produced. This force Fm must be able to keep the nucleus pushed downward in order to oppose Fp that pushes upward, so as to keep the transition seating of the air closed. The coil is sized according to these forces.



INDIRECT-ACTING ELECTRO VALVE

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.

DIGIT NUMBER 1	MEANING	Nachweis	DIGIT NUMBER 2	MEANING
0	No protection		0	No protection
1	Protection against solids with a diameter from Ø 50 mm	Ø 50 mm	1	Protection against vertically dripping water
2	Protection against solids with a diameter from Ø 12 mm	Ø 12,5 mm	2	Protected against dripping water when the enclosure is tilted up to 15°
3	Protection against solids with a diameter from Ø 2,5 mm	Ø 2,5 mm	3	Protection against rain water up to 60° from the vertical
4	Protection against solids with a diameter from Ø 1 mm	Ø 1 mm	4	Comprehensive water protection
5	Protection against dust in damaging quantities		5	Protection against water jets (Jet) from all directions
6	Dust-proof		6	Protection against powerful sea waves, or jets
			7	Protection against temporary immersion

The devices' protection degree is written on all the documentations, and is generally as IP65.

IP40 defines a protection against solid bodies with a rated diameter up to 1mm and no protection against water. IP65 defines total protection against dust and against water in every direction.
There are also regulations regarding the insulation classes referred to maximum working temperatures, according to C.E.I. standards 15 to 26.
All electro valves also report, together with their particular features, an indication of their ED insertion on their labels. If the label describes 100% ED data, this means that it is suitable for continuous duty.
Very often, reducing circuits that cut the peaks of return voltages, of very high value, at the moment of the de-energization (diodes in direct current and varistors in alternating current) are inserted in the connectors. We must remember that these devices do not protect electro valve solenoids, but the devices that control them (magnetic sensors, relays, etc.) protecting the contacts that could be damaged by these high voltage values. Moreover, luminous Leds denote the presence of the switching electric signal.

Insulation in accordance with the working temperature – Standard CEI 15-26	
Insulation class	**Temperature**
Y	90 °C
A	105 °C
E	120 °C
B	130 °C
F	155 °C
H	180 °C
200	200 °C
220	220 °C
250	250 °C

The maximum temperature admitted for a coil is conditioned by:

- Its own heating
- Temperature of the fluid that crosses it
- Room temperature

This data is referred to coils inserted in continuous duty.

14.5 DISTRIBUTOR FLOW RATES

The rated flow rate of a valve is identified by means of a ratio called flow rate factor, symbolized with a kv, that is produced by the amount of liters of water at a 18°C temperature that passes through it in a minute across the valve being tested, when the difference of pressure between inlet and outlet is equal to 1 bar.
The flow rate in liters per minute is associated to the kv factor by the following experimental formula:

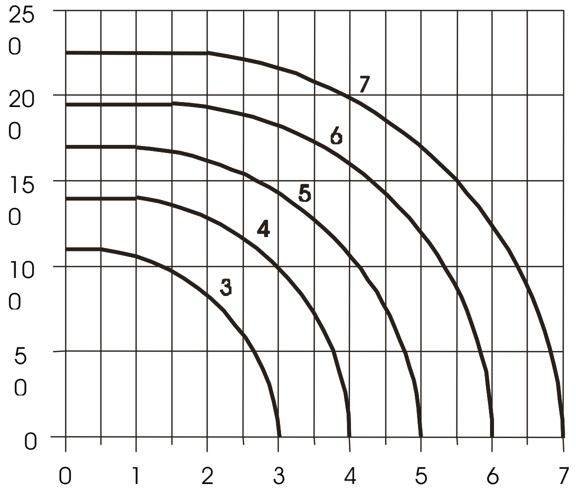
$$Q = \sqrt{\frac{\Delta P}{\theta}}$$

Where:

- **Q** is the flow rate of the liquid in l/min
- **ΔP** is the pressure drop across the valve
- **θ** is the density of the liquid in Kg/dm^3

But when the user wants to know the rated flow rate of the component in normal liters per minute, when at the valve's inlet there is a gauge pressure equal to 6 bars and to 5 bars at the outlet.
This data is stated in the equipment's technical datasheets. Certain diagrams that may also offer complete information are available also for operating pressures different from 6 bars.

Operating pressures are marked in the curves described in the following page. Imposing the ΔP between inlet and outlet we rise along the axis of the abscissas up to the curve with the chosen operating pressure and, horizontally, on the axis of ordinates, we can read the flow rate under those conditions. For example, if the operating pressure is equal to 6 bars, and at the outlet is 5 bars (ΔP = 1), the flow rate shall be about 125 Nl/min.
We can easily obtain the pressure drop between inlet and outlet if we know the flow rate and the operating pressure.



VALVOLE SERIE 105
M5 - 3/2 AND 5/2

Choice of the distributor

Once the cylinder has been chosen and its cycle-time has been decided, we must couple to it a valve that has a correct flow rate, in order to satisfy the imposed conditions. For example, if we must carry out a forward and backward stroke in 1 second with a 200mm stroke Ø 80 cylinder, we should proceed this way:

- Calculate total cylinder chamber volumes in dm^3
- Multiply the result by the cycles per minute
- Multiply by the absolute pressure.

The volume of the two chambers is 1.63 dm^3
The total demand shall be:

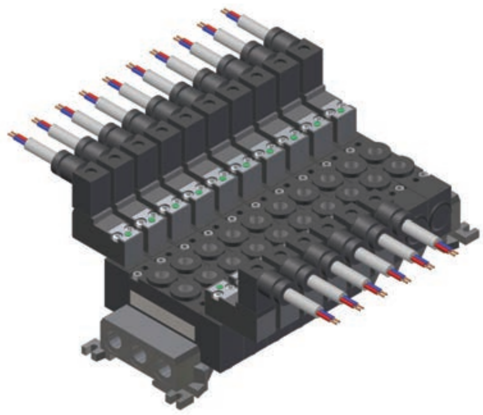
1.63 x 60 (frequency) x 7 (absolute pressure) = 628 Nl/min

We also use a safety factor K = 1.2 and find the flow rate needed for a operating pressure equal to 6 bars and ΔP =1.
The flow rate shall be about 820 Nl/min. We will choose a valve that meets the obtained flow rate value at least.

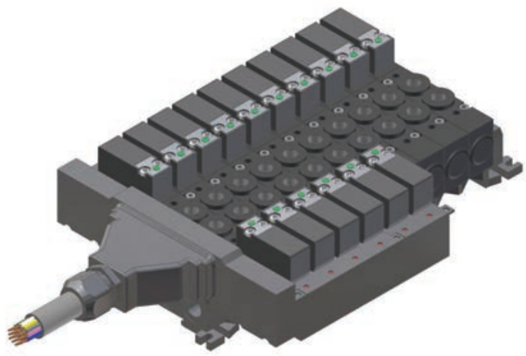
14.6 WIRING EVOLUTION

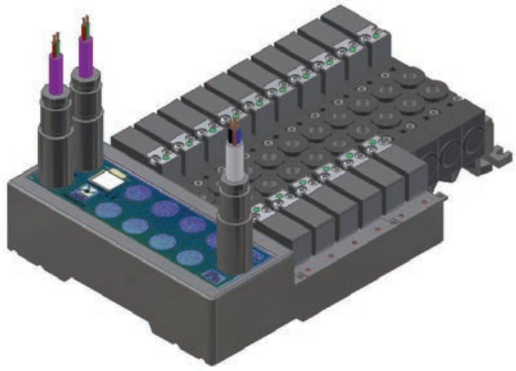
Automation development in all industrial sectors has increased circuit complexity conspicuously, also increasing assembly and wiring times. In order to reduce the labor costs, some electro valve islands are mounted in modules in series or batteries including, in many cases, electric connections are often supplied.

The traditional system establishes point-to-point connections with two electric wires for each electro valve of the series.

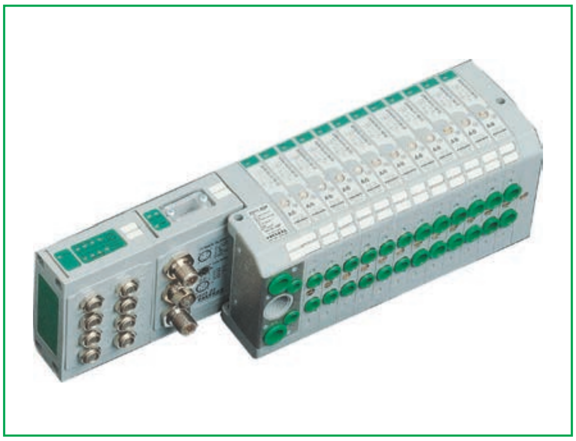


The advantage, in this case, is offered by reduction of assembly times referred only to the pneumatic part of the island.
Frequently, an already assembled wire extends up to the battery that contains all the necessary wires to connect each electro valve whose terminals are connected to a cup connector with female terminals.
The **multipolar connector** shall be connected to the battery in one single operation.

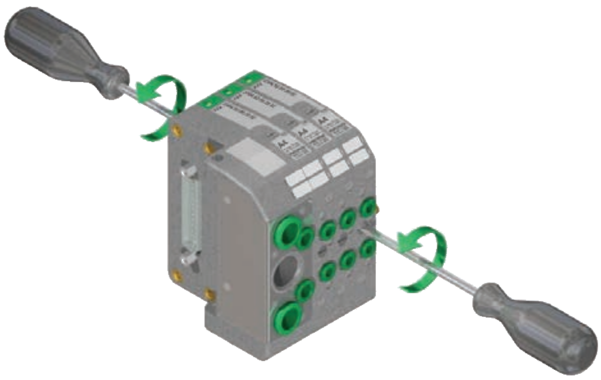




Reduction of the assembling times on the machine, also in this case, is evident.
The immediately following step is represented by a serial connection, where with only a two-wire cable together with the electric feeding, we are able to control the island with excellent results.
We will speak of these systems in the chapter dedicated to them.
The constant pursuit of flexibility and reliability has stimulated new generations of electro valves, which have also been created in order to satisfy the most sophisticated uses with their bulky dimensions increasingly reduced, without neglecting the aesthetic aspect, which currently results to be more and more agreeable.

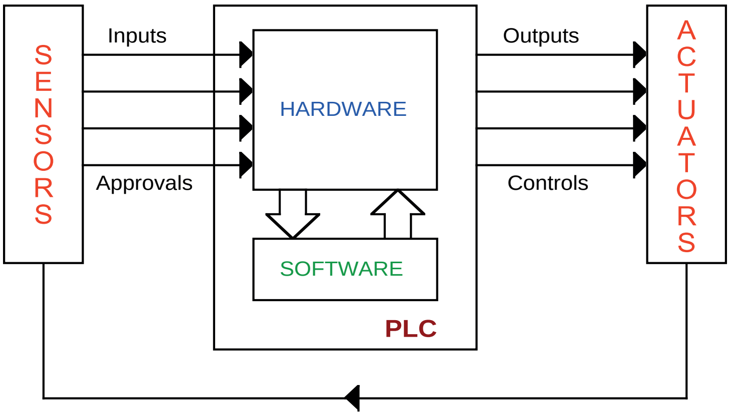


Batteries such as the one illustrated in the in figure, embody solutions for complex problems, and are extremely easy to use, offering the possibility of pneumatic and electric expansion obtained thanks to careful product design.



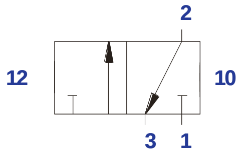
In fact, with a simple screwdriver it is possible to add a new “sliver” and expand the battery without any difficulty.

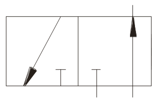
High-quality techno-polymers are used profusely allowing the batteries to reduce their weights even in those that have a high number of stations.
The PLC (programmable logic controller) manages these systems and it is convenient to use them whenever 10 or more systems including inputs (sensor signals) and outputs (electro valve signals) must be managed. Obviously, in addition to the electro valve island, they may manage other sophisticated equipment operations.

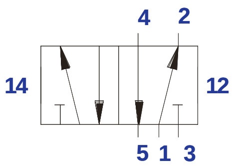


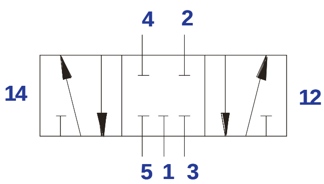
The figure represents a PLC's operating principle very simply. The choice criterions are associated to the maximum amount of inputs and outputs, to memory capacity, expandability, if this exists or does not exist, and to the management of serial systems, etc. Therefore, electronics is the prevailing interface with pneumatic systems; it manages the logic enabling the compressed air to have only the final function of power.

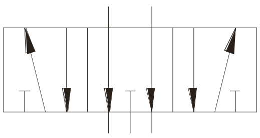
SUMMERY OF SYMBOLS

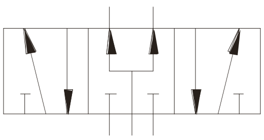


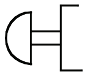


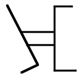


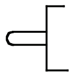


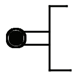


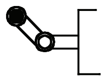


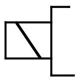


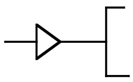


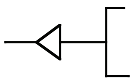


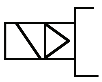












PNEUMAX

Chapter 15

AUXILIARY VALVES

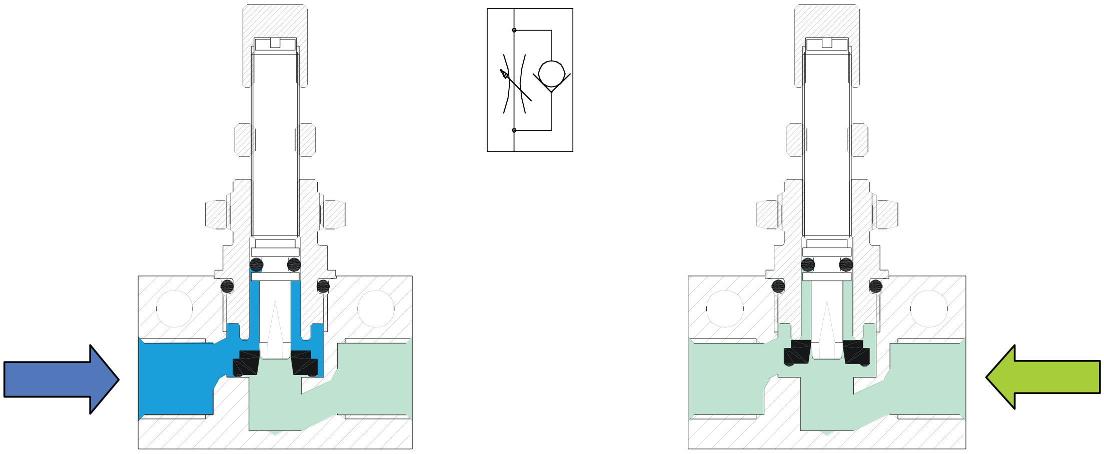
AUXILIARY VALVES

Auxiliary valves are called this way because they perform supporting functions to a circuit, as for example, select a signal, control a flow or transform a pneumatic signal into an electric signal, etc.

15.1 FLOW CONTROL VALVES

These valves perform the task of regulating cylinder speeds. They are substantially constituted by a variable throttle regulated by a knob that combines with a screw that closes or opens the passage opening gradually.

There are two types:
- Unidirectional
- Bidirectional

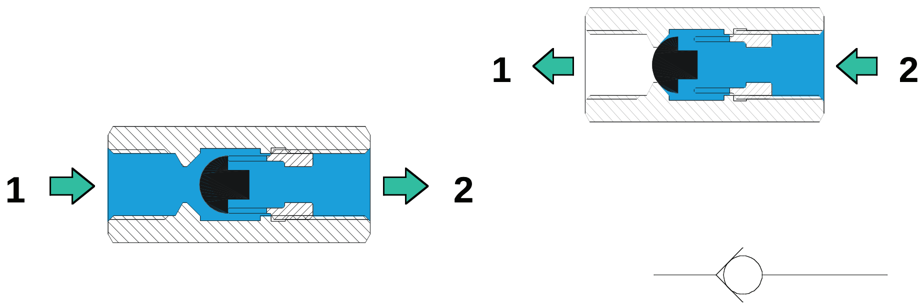


Regulated flow **Free flow**

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).

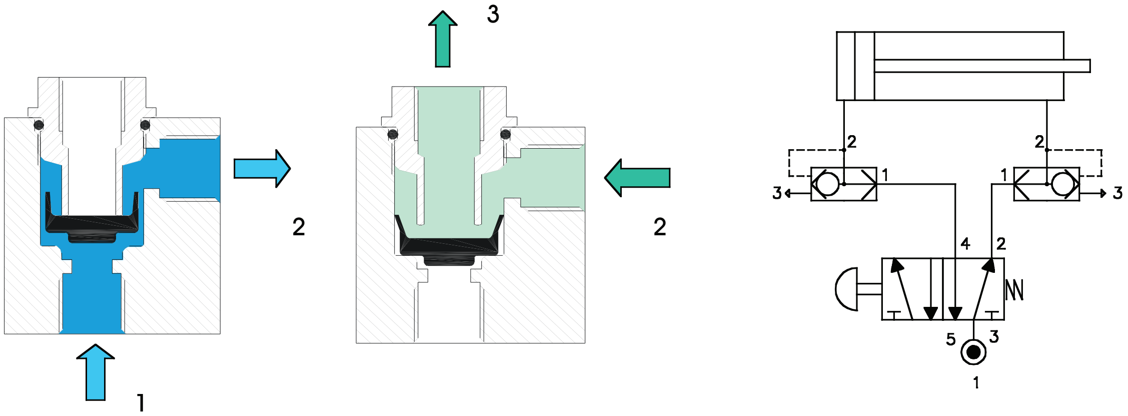
15.2 NON-RETURN VALVES OR UNIDIRECTIONAL VALVES

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.



15.3 DUMP VALVES (QUICK EXHAUST)

This component allows obtaining the maximum cylinder speed letting the air of the unloaded chamber flow directly to atmosphere, without having to pass across the tube and the valve in the exhaust's direction.
It is mounted on the cylinder ports.



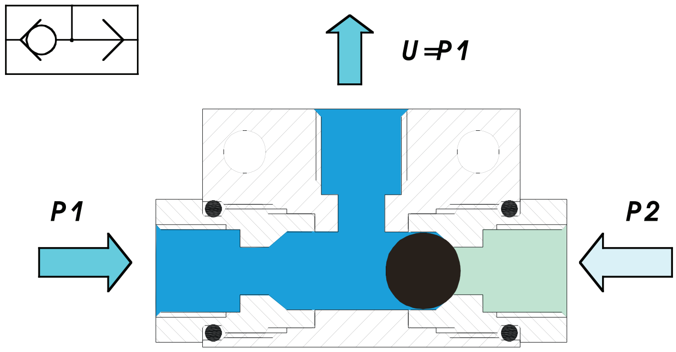
The figure illustrates the feeding phase toward the chamber of the cylinder in the left part of the image, and the unloading phase in the right part, including the valve/cylinder connection diagram.

15.4 CHECK VALVES

Check valves are devices that, depending on two signals in their respective inlets with equal or different pressure values, send the first incoming signal or the one with highest value if the valve is a high pressure selector, or the second incoming signal or the one with lowest value if it is a low pressure selector.

High pressure selector (OR)

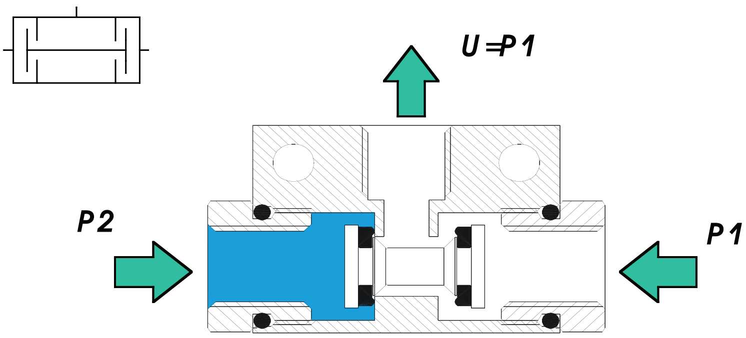
These are valves with two inlets and only one outlet, as illustrated in the figure on the following page.
The highest value signal prevails in pushing the cursor with respect to the lower value selecting it in the outlet. In case of equal pressures, the outlet selects the one that comes first. It may act as a logic **OR** function, as shown in the small table next to the figure. Outlet U has a high value when P1 also is present or when only P2 or both are present. The only value zero outlet situation is given when there are no inlet signals.



P1	P2	U
0	0	0
0	1	1
1	0	1
1	1	1

Low pressure selector (AND)

This valve also has two inlets and only one outlet:



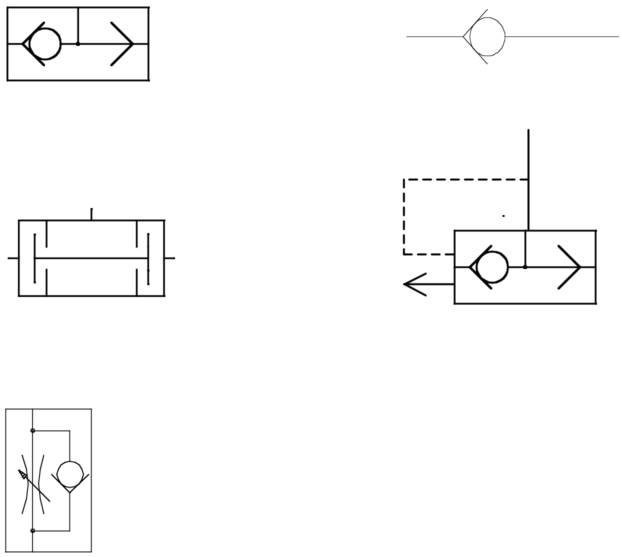
P1	P2	U
0	0	0
0	1	0
1	0	0

The selected signal present at the two entrances is the one with lowest value. In case of equal pressure values, the outlet shall select the one that comes in second place. In fact, if P2 has a higher value or comes in first, it shall push the cursor, closing the passage following the lower value or the one that comes in second place, to be present at the outlet exit. It may carry out the logic AND function as shown in the small table next to the figure.
We can see that the only outlet situation exists in presence of P1 and P2 at the inlet.

15.5 PRESSURE SWITCHES

Pressure switches are signal transducers. In fact, they transform a pneumatic signal into an electric signal. They are used to signal the presence of pressure or its absence, or rather, the one that has a value lower than the allowed one.
They may have fixed or variable calibration.
The fixed calibration pressure switch has a defined switching level that is always the same, while the variable calibration pressure switch has the possibility to be set at the desired value within a range of minimum and maximum values. Electric contacts may be closed, opened or exchanged.

SUMMARY OF SYMBOLS



Chapter 16

SERIAL SYSTEMS

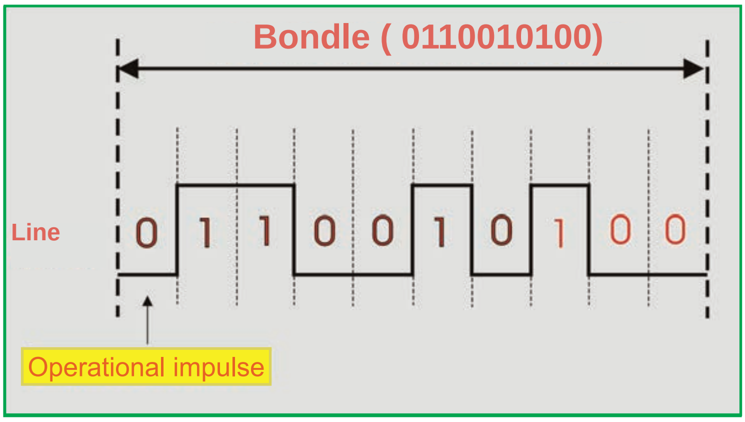
SERIAL SYSTEMS: DETAILS

The introduction of processors and electronic and IT evolution, together with pneumatics have contributed to progressive development of systems that are able to reduce costs drastically, resulting from assemblies and electric wiring. As mentioned before, there was a transition from point-to-point electric connections to multipolar connections for reaching then serial connections able to transmit signals with a two-pole cable normally.

Fieldbus

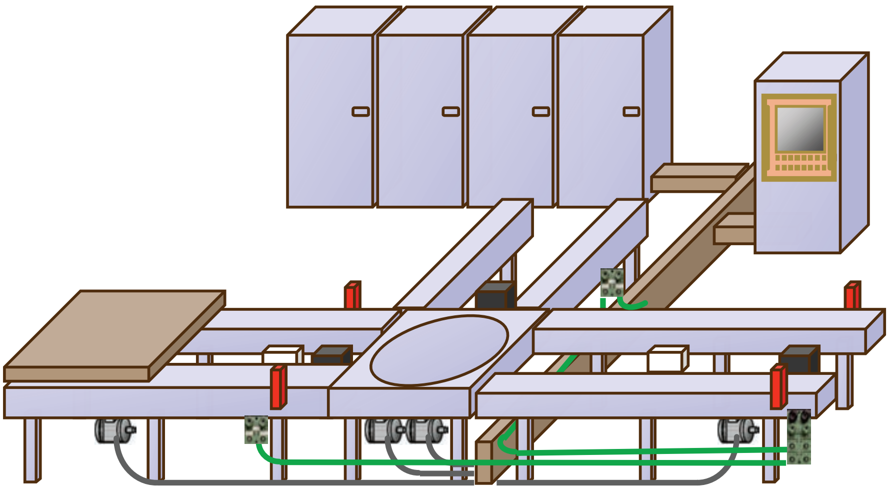
The (computing) bus is the public means of data transportation, while the field is the area where the communication takes place that may be an industrial complex or a single machine. Fieldbus is the term established by IEC (International Electro-technical Commission) that indicates a serial communication process between several devices and defined nodes.

By means of fieldbuses, the data is transferred with serial methods and not with parallel technologies, which means a bit after another at high speeds.

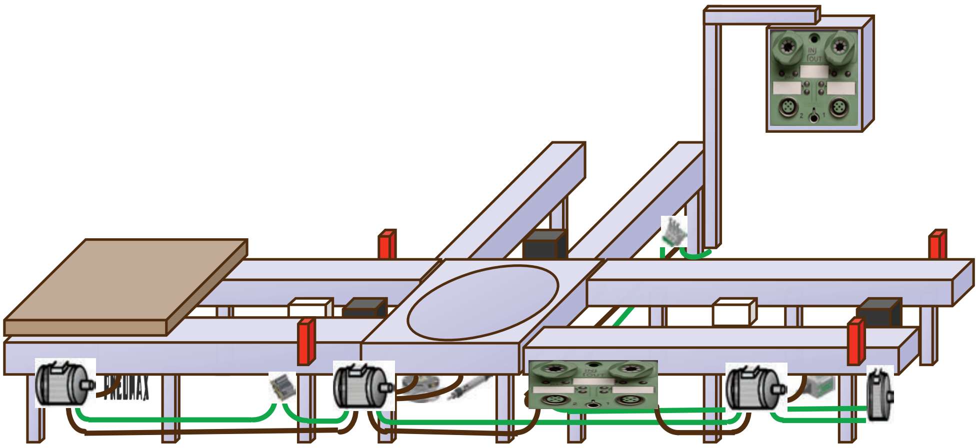


The main advantage consists in the need to reduce the amount of wires, constituted normally by two to four conductors in addition to the screening ones.
Its advantages may be summarized in the following points:

- Speed and wiring simplicity
- Reduced amount of I/O in the central unit
- Reduced electric board sizes
- Quick identification of damages thanks to advanced diagnosis functions
- Reduction of the supporting wire structures
- Ease to expand the system
- Possibility of connecting products from different manufacturers
- Global cost reductions



Traditional system



Serial technology system

The same system, as we can see, is reduced owing the elimination of the structures dedicated to the electric circuit system with parallel connections.

Communication protocols

The operating features and methods of any digital communication system may be extracted by the all specifications that define the communications “protocol”. We can say that a communications protocol is set of regulations and behaviors that two different entities must respect in order to exchange information between each other.

7	**Applications**	Transference of data among applications
6	**Presentation**	Formatting user’s data
5	**Session**	Definition of interfaces in order to use the transport system
4	**Transport**	Predisposition of the channel for data transport
3	**Network**	Definition of the data course within the network
2	**Data**	Definition of the data format and login type for their transmission
1	**Physical level**	Definition of transmission line and signal level features

The exchange is usually an operation that involves more intermediate phases, where each one is regulated by its own protocol. Each intermediate phase identifies its own communications process level and the set of regulations that govern its behavior. This is the protocol for that specific level.
When communications are performed among machines such as computers, field devices or similar, all the regulations, or rather all the necessary protocols, must be carried out strictly.

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.

Gateway: A bridge that allows two different protocols to be connected to each other.
Baud rate: Indicates the transmission speed of a communications system in Bits per second.
Interface: A standard used for electric signal transmission.
Serial Polling: Cyclic examination performed by the master to network nodes.
Time cycle: Total time employed by the master to update all the nodes.
Address: A number that allows identifying a node within a communications network.

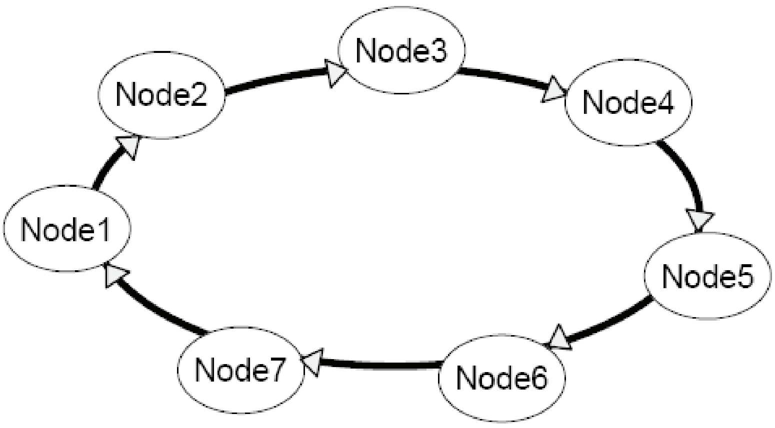
Network Categories

These are classified according to the way that a fieldbus is employed to interconnect nodes.
The most recurring models are:

- Ring
- Stern
- Linie

Loop Structure

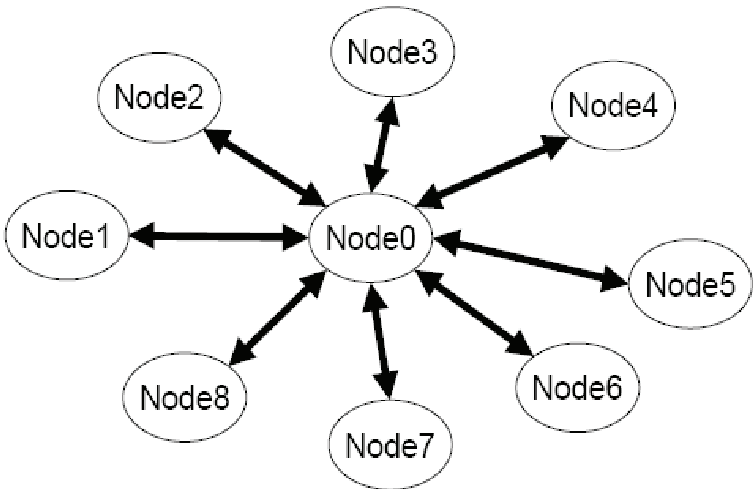
The loop structure allows connecting all the nodes in series. The slave that receives the message is in charge of repeating the received signal, as well as retaining those parts that are related with itself and sending any other information. The advantage of this system is that each node works as a repeater and regenerates the electric signal, thus covering significant distances such as 400 m between node and node reaching up to 13 km. The Interbus® protocol uses it. The disadvantage, that is not to be disregarded, is that if only one network component does not work or a part of its stretch is damaged, all the system stops.



For some uses, this is not a problem, but in most cases a similar situation renders the closed loop network useless. Inserting a new node between two already existing ones increases the unit's addresses, and therefore the programs need to be changed.

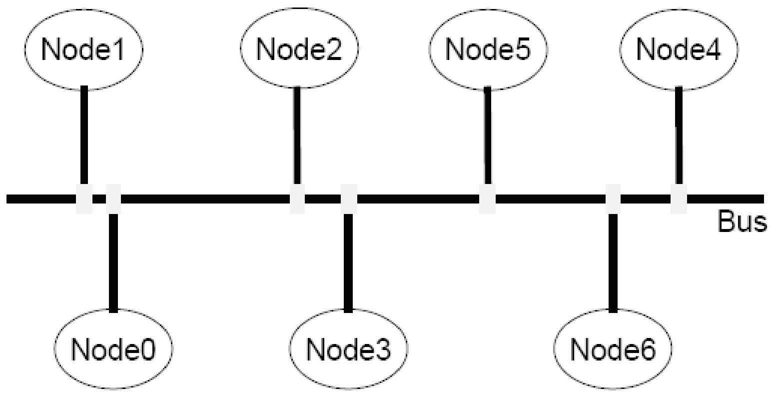
Star structure

The star structure is based on a network which has a central point from which the connection to each node begins. This configuration allows inserting a new node into the network easily and, in case a component is damaged, the other nodes are able to carry on their work. Line communications are bidirectional. But this kind of network requires a remarkable amount of wires. It is not used by the main fieldbuses. It is used in high-level networks such as Ethernet networks, for example.



Line structure

The line structure is the one used mostly in fieldbuses. The different nodes are connected in parallel hanging from the same line. This feature allows the nodes to operate even when some of them, at that moment and for different reasons, are not active participants. It is very useful especially for maintenance operations or in those cases where, for productive reasons, only a part of the system is required to work. The network may be easily extended at any point. This structure is used by the Profibus, **CANopen**® and **DeviceNet**® protocols.
Line communications are bidirectional.

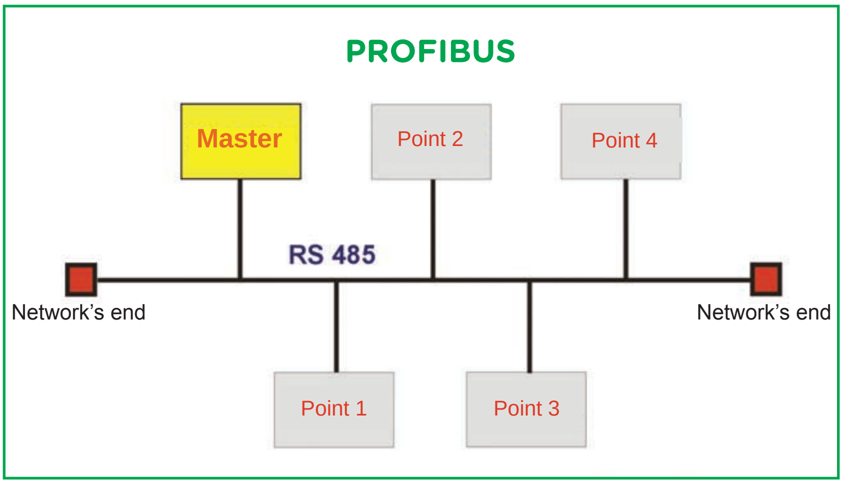


Transmission

The transmission is carried out by means of copper wires owing to their reduced costs and their valuable immunity to electromagnetic interferences. They support relatively high transmission speeds. Copper wires with special shape, as for example those used by the ASI Interface protocol, have been manufactured in order to simplify wiring operations.
Three standards are used to transmit electric signals serially:

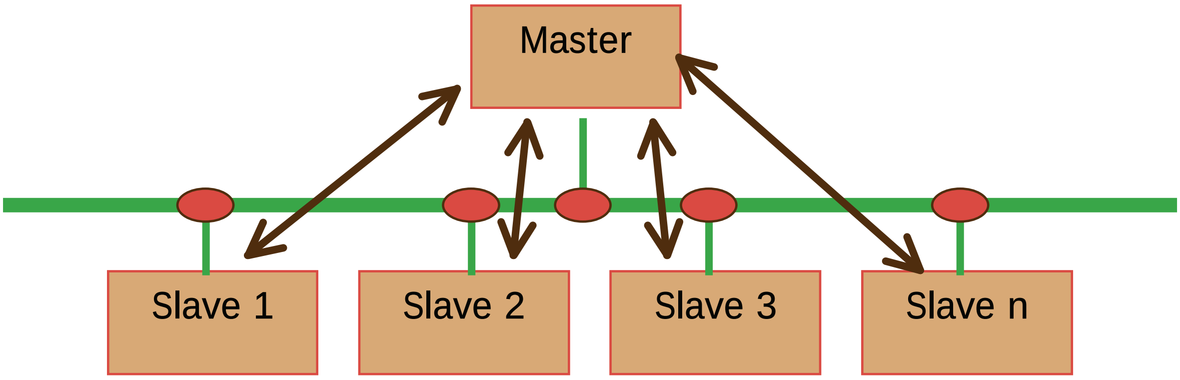
- RS-232
- RS-422
- RS-485

The first two standards are suitable for communications between two points, for example, the mouse is connected to the computer by means of a RS-232 interface. The RS-485 interface is normally used to connect a multi-user network such as a fieldbus, since it ensures high immunity to eventual electromagnetic interferences.
The digital signal at network's ends is broadcast at very high frequencies. Signal reflection may appear, an event produced by the return of the signal through the same line overlapping the original one and interfering with it.
Electric resistance terminals must be added to each network end, as shown in the example in the figure, in order to remove these reflections.



Bus access

Moreover, the fieldbus features the access mode, or rather, the way the master device and the slaves interchange information and regulate data traffic.
The easier way to establish the access mode is the master-slave architecture, which confers the managing role to only one single node in the network, the **master**, while all the other nodes are **slaves**.



The slave is receptive and only answers when polled by the master. Each network node has its own address. If the master wishes to collect information from the entire network, it must poll all the nodes simultaneously. Protocols which use this access mode are Profibus®, AS interface® and CAN.

Interbus®

INTERBUS

Interbus® was created by the German company Phoenix Contact and has been on the market for quite a few years now. It is used in Germany by the automotive industry.
The information starts from the only master, and travels across the connecting line in a single direction, reaching all network participants and returns from the participants toward the master. The cycle time is constant and does not need a configuring file since the master, after each ignition or reset, sends a sequence of messages that allows network self-configuration.
Each network node operates as a signal amplifier, and therefore, as previously said, allows covering large distances. The deactivation of any node is not possible during operation.

- Protocol according to the DIN 19258, EN 50254 standards
- Master-slave structure
- Transmission speed: 500 kbits/sec
- Maximum number of slaves: 256
- Maximum amount of inputs and outputs: 4096
- Closed loop connection
- Forward and backward RS 485 transmission using the same cable (4 wires)
- Distance between two nodes: 400 m
- Total bus length: 13 km

Profibus ®

Profibus® was developed by the German industry in collaboration with the most important universities. Siemens is its main supporter. Its employment in the automation sector is growing continuously. About 1200 companies distributed throughout 25 countries adhere to the international organization that supports Profibus®. Siemens offers a microprocessor in the market that is suitable to create a Profibus node.
The projected communication profile is the DP profile that is suitable for communications between PLCs and input/output units. There are other profiles such as FMS, suitable for communications that carry large amounts of data, as well as PA, that is an extension of DP designed to be used in areas with intrinsic security.
Communications between master and slave are known as polling communications. The master communicates cyclically with all the slaves simultaneously. The master needs a list of the participating nodes and a description of the devices in order to initialize the network. For this reason, Profibus DPR modules are supplied with a GSD file that describes the main features of the products. There are specific programs called configurators that support creating this list.
Disconnecting a node is possible without interrupting communications with the other active participants.
The maximum distance between the first and the last component varies between 100 and 400 m.
Transmission speeds are established directly during configuration and are transmitted automatically to all the devices.

- Protocol according to DIN E 19245 EN 50170 standards
- Master-slave structure
- Transmission speeds from 9.6 kbits/sec to 12 Mbits/sec
- Maximum number of participants: 32 (126 with a repeater)
- Line structure connection
- Serial RS 485 interface with two wires
- Total bus length at maximum speed: 100m
- The network requires electric resistance terminals
- Configuration file.*GSD

CAN

The CAN system (Controller Area Network) has been developed by Bosch with the purpose of reducing wiring inside motor vehicles drastically. The bus is very fast because the communications protocol is simple and the messages are short. Use of CAN has spread from the automotive sector to all industrial sectors, and particularly, to the low level of sensors/actuators.
Differently from Profibus and Interbus modules, that are purchased complete, in this case these microprocessors can be purchased on the market and the software can be created using the specifications for each protocol.
Starting from Bosch CAN, several standard protocols have been created, of which the two most important ones are:

- **CANopen®**
- **DeviceNet®**

CANopen®

CANopen® is the most popular among all fieldbuses. The reference entity is CIA (CAN in Automation), based in Germany.
In a CANopen® network, each device must have an address and its assignment is carried out during the installation.
The baud rate must also be established, having to be equal for all the nodes and it must consider the line's length.
Each manufacturer must supply an EDS file (Electronic Data Sheet) in order to describe the features of the device and the implemented objects.
Additionally, a node may be disconnected under this protocol without interrupting communications with the other active participants.

- Protocol according to ISO 11898 EN 50325 standards
- Master/slave structure
- Transmission speed from 10 kbits/sec to 1 Mbits/sec
- Maximum number of participants: 128
- Line connection
- Serial RS 485 interface with 2 wires and a common wire
- Maximum bus distance (see table)
- The network requires electric resistance terminals
- Configuration file *.EDS

Length of cable:

- Up to 40 m	Baud rate	1.000 kBit/sec
- From 40 to 300 m	Baud rate	500 kBit/sec
- From 300 to 600 m	Baud rate	100 kBit/sec
- From 600 to 1.000 m	Baud rate	50 kBit/sec

DeviceNet®

DeviceNet® was introduced by the PLC manufacturer Allen Bradley. The reference entity is ODVA (Open DeviceNet Vendor Association), an independent organization that is in charge of managing and promoting the protocol worldwide. Additionally, DeviceNet® allows the nodes to be inserted and removed without any interruptions.

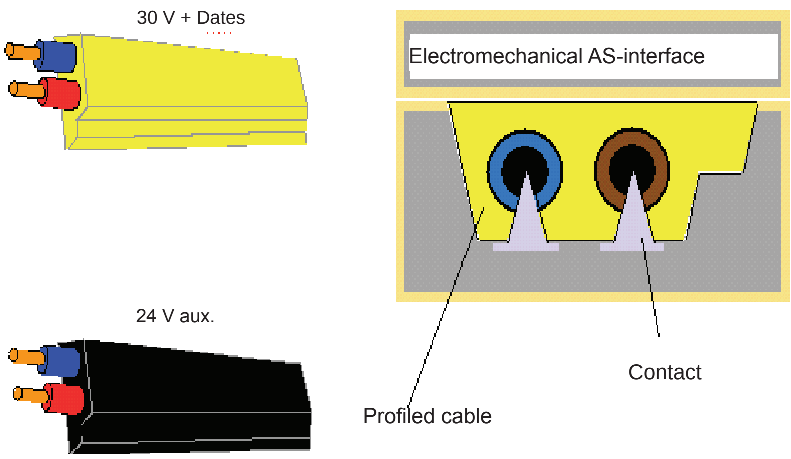
- Protocol according to ISO 11898 part A- standards
- Master/slave structure
- Transmission speed: 125-250-500kbits/sec
- Maximum number of participants 64
- Line connection
- Serial RS 485 interface
- Maximum bus distance (see table)
- The network requires electric resistance terminals
- Configuration file *.EDS

Length of cable:

- Up to 100 m	Baud rate 500 Kbit/sec
- From 100 to 250 m	Baud rate 250 Kbit/sec
- From 250 to 500 m	Baud rate 125 Kbit/sec

AS-Interface (AS-I)®

The AS-I® (Actuator Sensor Interface) system was born in 1994, and is a communications network designed only to connect industrial devices such as sensors and actuators. The protocol's simplicity allows integrating both the control signals and the feeding to the nodes in one unshielded cable. It is a yellow cable with a particular shape that has become the symbol of this protocol.
The cable has an insulation piercing connection. The connector's pins receive the signal without need of removing the sheath from the wire. The cable's configuration prevents reverse polarities. If the cable has a length greater than 100 m a repeater, which extends the network's length to 300 m, must be included. The maximum flow rate of the yellow cable is 2 A; if the consumption of the electro valves should be higher than that value, a second black cable which brings 24V DC to the outputs must be added. This cable also uses the same wiring method.



Access to the bus used by AS-I is made using the master/slave mode, which may be inserted with a PLC or a PC, or else, using a Gateway. The Gateway works like a translator from an upper protocol into the bus AS-I. There are Gateways for all main protocols. In the AS-I network it is necessary to plan the presence of a dedicated feeder that supplies a specific voltage in order to transmit the data. Specific equipment, found on the market, allows an address to be assigned it. Each slave may handle a maximum of 4 inputs and 4 outputs, and the maximum number of slaves is 31.

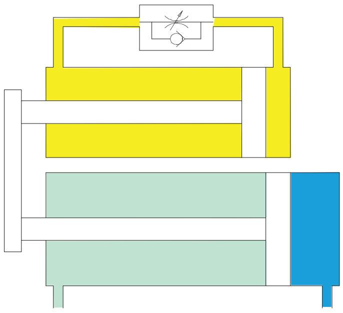
- Protocol according to EN 50295 standards
- Master/slave structure
- Maximum transmission speed: 167 Kbit/sec
- Maximum number of slaves: 31
- Line connection
- Maximum bus distance: 100 m

Chapter 17

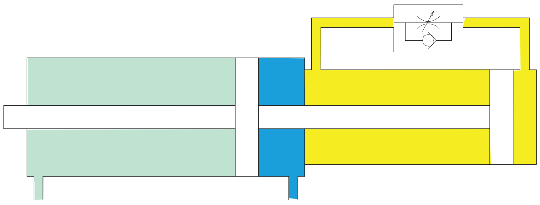
HYDRAULIC CONTROL SYSTEMS

HYDRAULIC CONTROL SYSTEMS

Operating conditions that the devices are not able of carrying out may appear during many uses of the systems. One of these is the advance of the rod of a cylinder at low and constant speeds. We have already approached this matter and the conclusion was that obtaining the mentioned conditions is not possible, without intervention. Pneumatic cylinders work under satisfactory results with regulated speeds up to about 20mm/sec. with respectable motion uniformity. Under this value, the typical skipping advance is produced.
The reason for the difficult speed control in a pneumatic cylinder depends on the fact that we are controlling a compressible fluid which may be influenced by external factors. Mixed air and oil systems are used to this purpose. There are many possible solutions, but the most used one, due to its easy employment, is constituted by the so called closed circuit hydraulic brake. This kind of solution is cheap because it does not require the use of completely hydraulic systems which can be expensive.

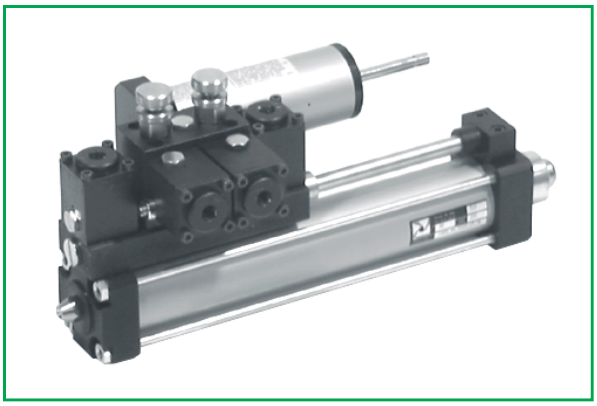


Parallel Connection

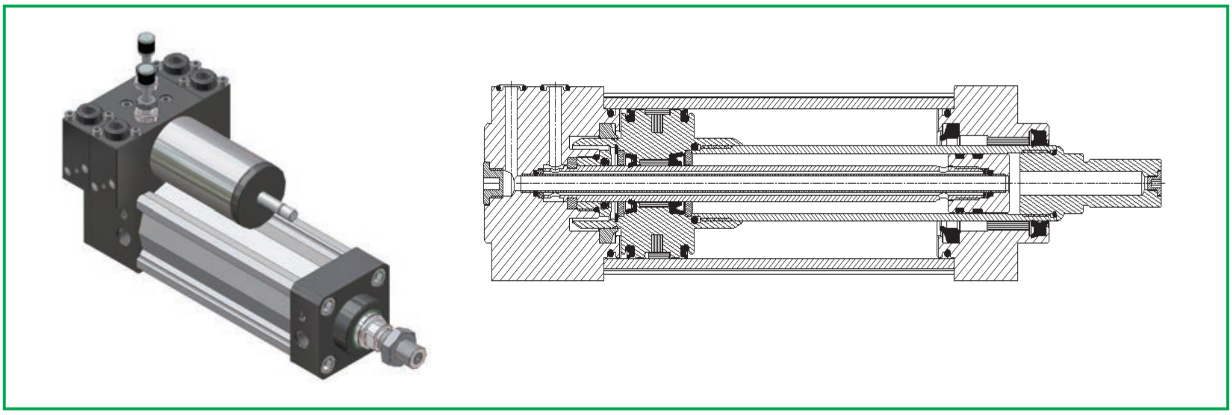


Serial Connection

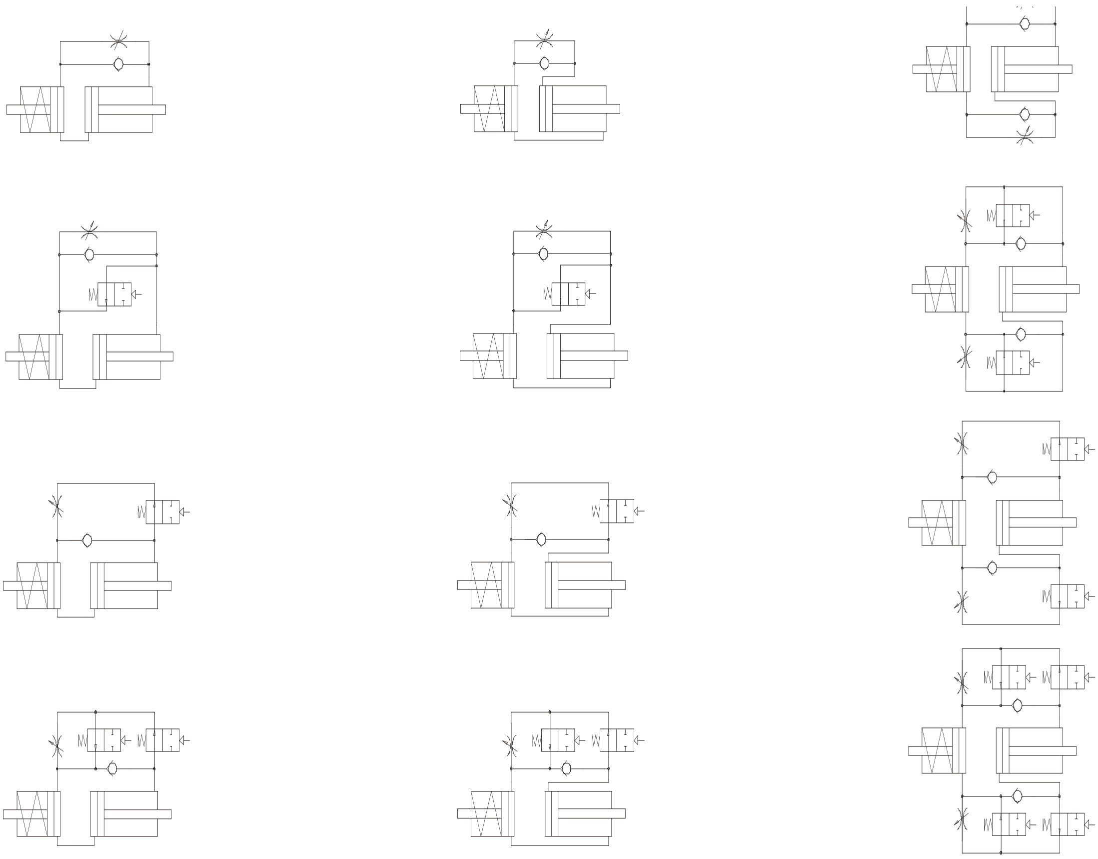
The two figures show the device connected to a pneumatic cylinder in a parallel or a serial version. During its motion the pneumatic cylinder drags the rod of the brake full of oil, which transfers the fluid from one chamber to another one transiting across a flow regulator.
Therefore, the speed of the 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.



The operating principle remains identical; the difference is that the hydraulic control circuit is obtained using the space inside the hollow rod of the pneumatic cylinder. This solution penalizes somewhat the force expressed by the cylinder in the return stroke, because the rod has a larger diameter than the standard one, just to obtain this circuit inside itself.



Functions per rod in outlet **Functions per rod in inlet** **In both directions**

The combinations may be obtained in all the versions of the hydraulic brake. We must note that strokes over 500mm may be subject to constructive difficulties.

Chapter 18

SEALING ELASTOMERS AND GASKETS

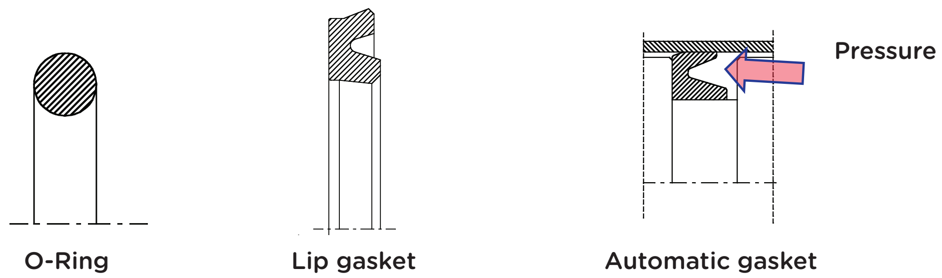
ELASTOMERS

The term elastomer defines any component manufactured with a material that has the feature of possessing "elastic memory", which means returning to its original shape after being compressed. This feature is typical of rubber.
Therefore, elastomers define generically sealing elements or gaskets, commonly used to manufacture compressed air equipment. This matter is wide and complex; therefore, this chapter has the intention of supplying useful instructions regarding the functions and features of gaskets.
The gaskets are used in order to obtain:

- Static seals
- Dynamic seals

Static seals are referred to those elements among which there are no relative motions, that are interposed between two parts and, for elastic deformation in compression, they perform a watertight function. They generally have a toroidal section (O Ring) and are available in different sizes according to their section, diameter and material.

Dynamic seals are performed when bodies with mutual relative motion are involved and the gaskets move together with one of them.
In this case, the sliding motion along the involved surface of the gaskets causes friction. Friction depends on several factors such as the type of the material employed, its hardness, quality of the sliding surface, etc., and the use of lubricants. The lubricant also acts as a sealer and, in addition to creating a thin layer between the gasket and the surface, guarantees a hydrodynamic system that prevents direct contact between the bodies in related movements. The behavior of the gaskets depends much on their geometric shape, on their size and on the material with which they are manufactured (mixture).
In dynamic seals, the use of O Rings is quite low because the wear compensation is limited to compression. Instead, the lip seals are largely used with the typical U section which is ideal for radial seals. They are also called "positive acting" or "automatic" because they widen and squash themselves on the surface with which they are in contact when subject to pressure. But the friction tends to increase when the radial load increases. Wear compensation is very effective. In opposition to O Rings that allows double seals, automatic gaskets must be combined with two others opposed to them. There are also different solutions that include the double seal function in their manufacture. An example is the integral gasket which is constituted by a metallic disc where the rubber with double-lip shape is vulcanized.



Tricks like the rounding of sharp edges are performed on the lip gaskets in order to avoid undesired effects, such as scraping the lubricating grease on the sliding surface. Therefore, elastomers are constituted by elastically deformable materials.
They are divided into:

- Elastomers
- Plasto-elastomers

Elastomers are produced using rubber that is mixed with additives and is then vulcanized at high temperatures, and therefore it acquires elasticity, being a material with plastic features. Sulfur is the usual vulcanizing agent. Physical, chemical and thermal features may vary notably according to the amount of rubber and the additives added to the initial mixture.
Plasto-elastomers are also called thermoplastic rubbers, and generally act as elastomers up to temperatures not higher than 80°C. At higher temperatures they act as elastomers becoming warped plastically under the action of forces.

A body is elastically deformable when, after being deformed under pressure, traction or twisting, it returns to its original shape. If this deformation remains, we can speak of a plastic or viscose deformation.
An important feature is the **hardness** measured in Shore A and it represents the resistance found by a ball tip with a proper diameter, when perforating the surface of a test part when it is charged with a known weight.
Instead, the **modulus of elasticity** is the load necessary to produce a determined percentage and reversible stretch in the test part.
Mechanical wear compensation of the surface of a test part is called **abrasion resistance**. The eroded body is made with granular materials, and is pressed against the surface with a known force in relative motion. It is expressed like the abrasion resistance ratio.
When the initial dimensions are not completely retrieved, after having subjected the test part to a load, we can speak of **residual deformation**. The non-retrieved deformation is called "permanent set". While a "compression set" is produced when a test part is subjected to a compression without the residual deformation remaining.
The mixture formulas must satisfy the needs of use, and obviously, different mixtures shall offer different performances that the manufacturer must state together with the guarantee of their continuity over time.
The different situations of use of pneumatic equipment demand the employment of gaskets with different mixture formulas. These formulas must offer the guarantee of duration and performance for each specific need.
The common materials used for pressing gaskets with several shapes in the pneumatic sector are those which follow:

– Acrylonytrile butadiene rubber	NBR
– Hydrogenated acrylonytrile butadiene rubber	HNBR
– Fluoride Rubber	FPM
– Polyester Urethane rubber (Polyurethane rubber)	PU

NBR

It is a Butadiene and Acrylonytrile polymer.
The percentage of Acrylonytrile varies between 20 and 50%. A greater Acrylonytrile percentage favors better behavior toward mineral greases and oils but causes decrease of their elasticity, makes their behavior at low temperatures worse and stresses residual deformation. It has good compatibility also with vegetable and animal oils and with fuels (gasoil), and a good behavior with water up to 100°C and with low concentration inorganic acids. The average thermal field for its use goes from – 30°C to +100°C.

HNBR

It uses the basic formula of NBR with the addition of hydrogen.
It keeps all the features of compatibility of the basic mixture with a wider thermal

field of use toward high temperatures, from -30°C to +150°C. Also, abrasion resistance is improved.
It is a mixture known with the trade name of THERBAN.

FPM

It is a fluorine based mixture with high thermal resistance and chemical stability.
It is a fluorine based mixture with high thermal resistance and chemical stability. Special mixtures are necessary for uses in hot water and vapor.
The thermal field of use varies from -20°C to +200°C.
The elastic memory is lower than the nitrite mixtures.
It is marketed with the VITON name.

PU

It is an organic material with high molecular weight commonly called Polyurethane, whose chemical composition is featured by a high amount of Urethane groups. Within determined temperatures it has elastic features just like rubber. It has a good abrasion resistance. It resists oxygen and ozone very well and its volume does not increase when in contact with oils, mineral greases and mixtures of water and oil. It does not resist acids, alkalis, solvents and break liquids. It may have hydrolysis phenomenon in presence of water with temperatures near to its maximum working temperature. Its thermal field of use goes from -30°C to +80°C.

These are the general features of the materials used to manufacture gaskets. It is fitting, per application, to consult the producers' technical manuals in order to obtain the most detailed information regarding their use.
When lubricant is used, be careful when introducing oil that is compatible in the device with the used mixtures.

Chapter 19

VACUUM

VACUUM

Vacuum is defined as the condition of a space free of matter or which contains only rarefied gases.
The earth's atmosphere exercises on the planet surface, at the sea level, a pressure equal to 101 kPa (1.013 bars). The value of this pressure is influenced by altitude, for example, at a height of 3000 m the pressure is equal to 70 kPa.
Atmospheric pressure is strictly correlated with vacuum.
Vacuum is produced when the pressure value is lower than the atmospheric value, and absolute vacuum is produced when there is no atmospheric pressure.
The law of perfect gases (Boyle – Mariotte) states that at constant temperatures the pressure P is inversely proportional to the volume V, or rather, when the volume increases the pressure decreases.

$$P \times V = \text{cost.}$$

The vacuum level is the measurement for negative pressures, and it may be expressed using different measurement units (bar, Pa, Torr, mmHg, % of vacuum etc.).

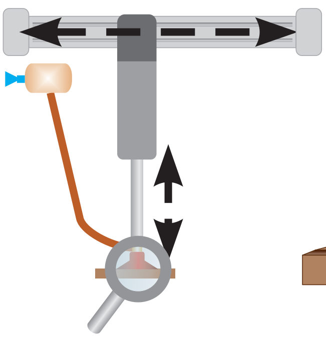
Vacuum is employed in three main fields:

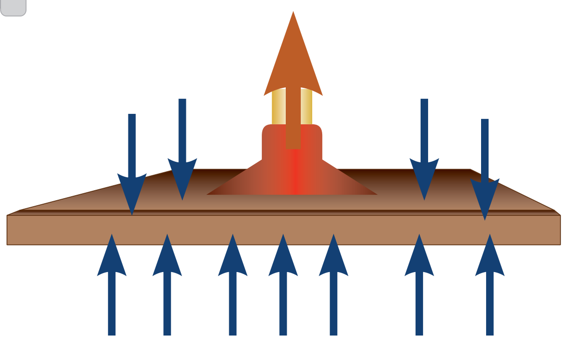
- Blowers or rough/low vacuum (from 0 to -20 kPa) for ventilation, cooling and cleaning

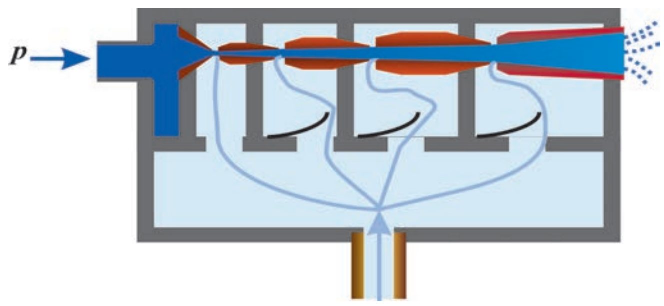
- Industrial vacuum (from -20 to -99 kPa) for lifting, handling and automation

- 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.







Multi-stage ejector

The following table describes the conversions between the different measurement units and their equivalents for different values:

- 1 Pa = 0,01 mbar
- 1 kPa = 10 mbar
- 1 torr = 1,333 mbar
- 1 mmHg = 1,333 mbar
- 1 mmH2O = 0,098 mbar
- 1 PSI = 69 mbar

Vacuum mbar	Vacuum %	Vacuun kPa	Vacuum mmHg	Vacuum torr
0	0	0	0	0
-100	10	-10	-75	-75
-133	13,3	-13,3	-100	-100
-200	20	-20	-150	-150
-267	26,7	-26,7	-200	-200
-300	30	-30	-225	-225
-400	40	-40	-300	-300
-500	50	-50	-375	-375
-533	53,3	-53,3	-400	-400
-600	60	-60	-450	-450
-667	66,7	-66,7	-500	-500
-700	70	-70	-525	-525
-800	80	-80	-600	-600
-900	90	-90	-675	-675
-920	92	-90	-690	-690

The degree of vacuum must be limited to the need for vacuum because it requires high energy consumption to generate vacuum.
It is important to know the consumption of the ejectors used in the system in order to choose the compressor. For example, if a pneumatic pump consumes 2 Nl/sec when fed at 6 bars, the compressor must be able to supply at least 2 x 60 = 120 Nl/min. The power supplied by the pump is the product between flow rate in suction and the vacuum level:

Power = flow rate x vacuum level

The power supplied is strictly associated to the size of the pump and it allows us only to understand at which vacuum level it is preferable to operate and not to compare two different pumps. But if we know the air consumption of the ejector and the suction flow rate, we can calculate the efficiency independently from the pump's size.

$$\textbf{Efficiency} = \frac{\textbf{Supplied flow rate}}{\textbf{Consumed flow rate}}$$

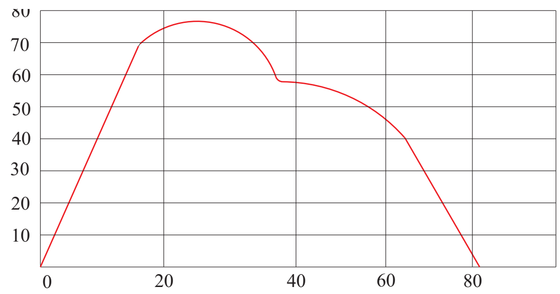
Representing the value of the efficiency at different vacuum levels, we can identify which pump uses the absorbed energy better during the different operating conditions.

Flow rate [Nl/s]	Vacuum degree % [-KPa]	Supplied power
10,9	0	0
5,7	10	57
3,8	20	76
2,5	30	75
1,4	40	56
1,1	50	55
0,8	60	48
0,48	70	33,6
0	80	0

When a manipulation system based on vacuum is created, a sufficient force for safe handling must be produced.

To this purpose, the role of the suction cup is very important.

SUPPLIED POWER



Vacuum degree [-kPa]

Suction cups

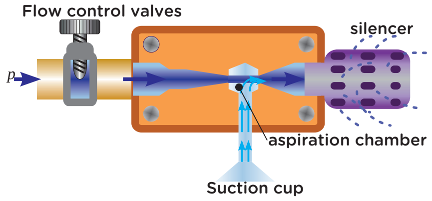
The drawing unit in vacuum systems is the suction cup. It produces its action due to the fact that the surrounding atmospheric pressure pushes it against the object to be held.
The force which keeps the object pushed against the suction cup is caused by the difference of atmospheric pressure and the internal pressure of the suction cup, and it grows proportionally to this difference. The choice of suction cup is determined by the weight, shape and material of the object to be moved and by the gripping position.
The practical force produced from which the size of one or more suction cups depends, is defined by the following formula:

Produced practical F = Theoretic force / k

where k is the safety ratio to be considered according to the gripping type:

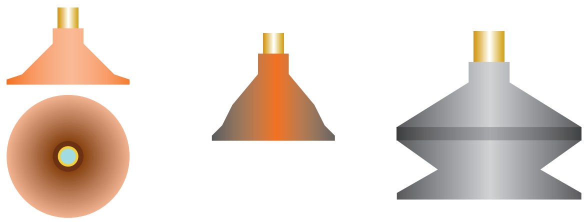
- k = 2 for horizontal parts for low speed movements
- k = 4 in case of high speed or vertical movements

The theoretical force produced by the suction cup is: **F = area x P**

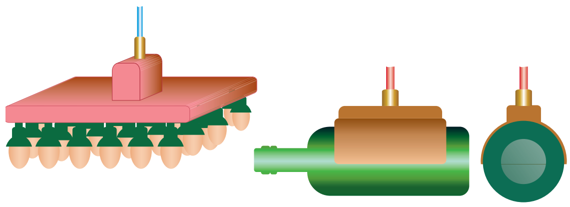


Where P is the difference between the external pressure and the pressure between suction cup and the surface of the object.
During the loading movement, we must consider the additional efforts produced by the application, such as accelerations, decelerations, etc., which could further influence the choice of the number and diameter of the suction cups.

The friction ratio changes according to use, and this may determine variations of the suction cup's gripping capacity.
Once the practical force's value has been calculated, we can choose the suction cup according to its features.
The flat suction cup is widely used in current employments.
It is used, in the different versions proposed by the manufacturers, for horizontal and vertical movements of parts with flat or slightly wrinkled surfaces such as those of glass and metal, or for moving thin and light objects such as paper sheets. The length of the connecting tubes between suction cup and pump must be highly limited in order to decrease ejection times. In many cases, we can fix the ejector directly on the suction cup and make it move together with it thanks to its reduced weight.
The air volume to be ejected is reduced to minimum needs, this way improving the system's response times.

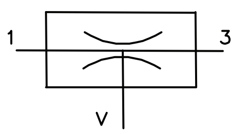


Bellow suction cups are used to lift objects with irregular surfaces, such as corrugated sheets or plates, or in order to compensate light differences in level.
The amount of waves or sectors makes it suitable to compensate the more or less stressed differences in level; as high is the amount of the waves, as high is the diffe-rence in level to be compensated. They must not be used absolutely for vertical grips.
Oval suction cups are used for tight and flat objects, because they substitute a series of suction cups with small diameter.

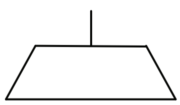


When sizing the system, we must necessarily consider the features of the object to be handled. The calculation method in fact is very different in case the object is porous (cardboard, wood) rather than "fixing". The suction cup must produce a suitable force in order to handle an object with fixing materials safely. To this purpose it must work at the right vacuum degree and have the right size. With these materials, it works with a vacuum degree of about -60 kPa.

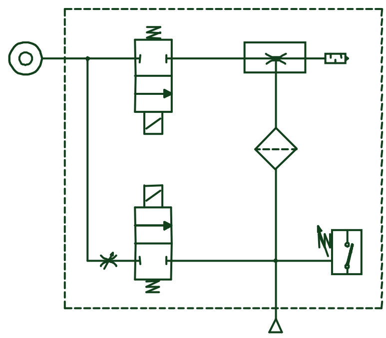
When the time for transporting the part is relatively large, we recommend equipping the vacuum generator with a non-return valve, which allows reducing compressed air consumption allowing deactivation of the feed electro valve as soon as the depression level is reached. This valve has the purpose of keeping the created vacuum when the electric feeding is interrupted. The generator must be equipped with a vacuum switch because, if during the transport there is a leak in the vacuum circuit, there shall be a depression reduction which shall be detected by this circuit.
The inlet electro valve shall be activated again in order to realign the depression.
It may also be equipped with a blowing valve that breaks the vacuum, ensuring safe release of the part.
To transport porous materials, the pump must compensate moment by moment the leakage flow due to the porosity of the material. The leakage flow by means of the material is strictly associated to the size and features of the suction cup, as well as to those of the material. Therefore, the pump must be chosen simultaneously with the suction cup. Generally, works are carried out at a low vacuum levels, exploiting to a maximum the power supplied by the pump or suction cup system, which means that when the combination of ejecting flow rate and produced vacuum allow the suction cup to express its the maximum force. Since the force produced increases when the supplied power increases, extending the diameter of the suction cup the vacuum level may be reduced. This is due to the fact that the extension of the area exposed to the vacuum is wider than the reduction of the vacuum level. Therefore, the size of the pump or the working pressure may be reduced producing more force than what is needed, with a remarkable saving of compressed air consumption.
Generators which are currently manufactured modularly adapt themselves to automated processes easily, thanks to the integration of several accessories such as feeding electro valves, blowing devices, control vacuum switches, non-return valves, etc.
The vacuum switch allows the detection of the produced depression level, confirming the value of the part's retention force by activating an electric contact. It may be compared to the pressure switch for uses with positive pressures.
Blowing devices allow decreasing the times of the part's release, and they intervene automatically, as soon as the working pressure is interrupted, by means of a certain volume of compressed air released by a capacity, or thanks to an electro valve which opens a transit of compressed air toward the suction cup. Usually, the system is completed inserting a suction filter and a vacuum gauge to measure vacuum.



Ejector



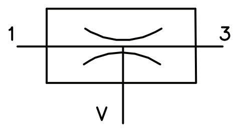
Suction cup



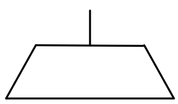
Modular generator

Vacuum lines with important sizes are activated or intercepted with proper sized devices. Also in this case, as in pneumatics, shutter valves or electro valves are used when remarkable flow rates are involved.
The switching control may be governed either by vacuum or by positive pressure. When using pressure, the pilot portion is separated and watertight from the valve body through where the vacuum transits. The feeding for the piloting is supplied directly by a line with dedicated positive pressure, and the switching is carried out as in pneumatic valves and electro valves.
Whenever piloting with vacuum, the portion of the solenoid valve is self-fed by vacuum in the valve body. In this case, a specific solenoid must be used.

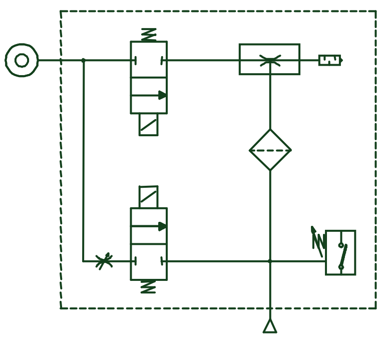
SUMMERY OF SYMBOLS



Ejector



Suction cup



Ejector complete with:

Suction filter
Vacuum switch
Feeding electro valve
Blowing electro valve
Muffler

Chapter 20

PROPORTIONAL REGULATOR

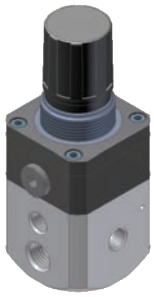
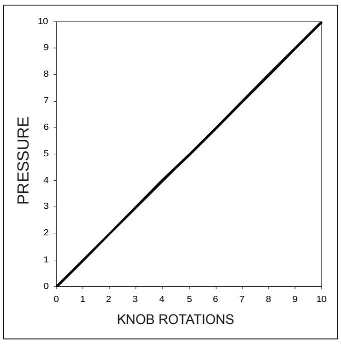
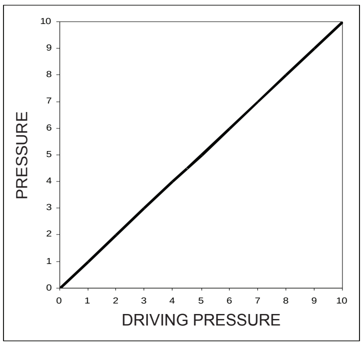
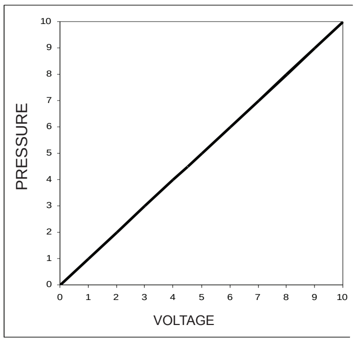
PROPORTIONAL REGULATOR

Introduction

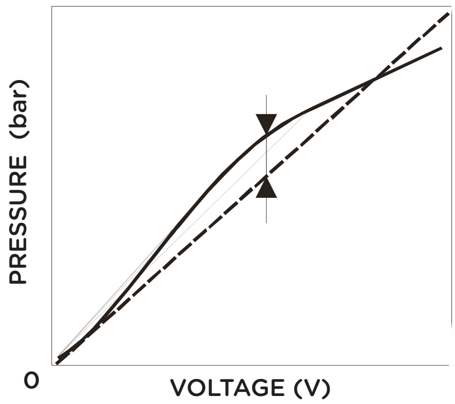
Modern industrial applications require higher performance of their pneumatic components. When we are required to intervene on the parameters which determine the produced force and the actuating speed, modifying their values dynamically, we must act on the pressure and flow rate values of the equipment installed on the machine.
The traditional method exploits the pneumatic logic associated to the employment of valves fed with different pressures, which release pressures previously set up once they are activated.
To this purpose, we need an alternative solution, which solves the problem, with reduced size and acceptable costs.
A proportional regulator with electronic control satisfies this need.

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.

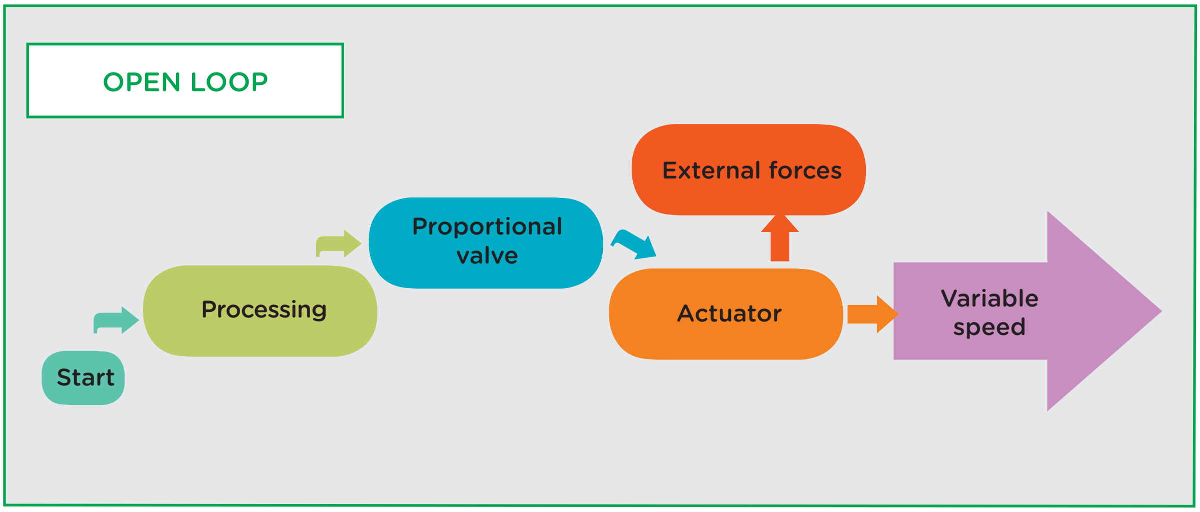
Mechanic	Pneumatic	Electric
		
		

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.

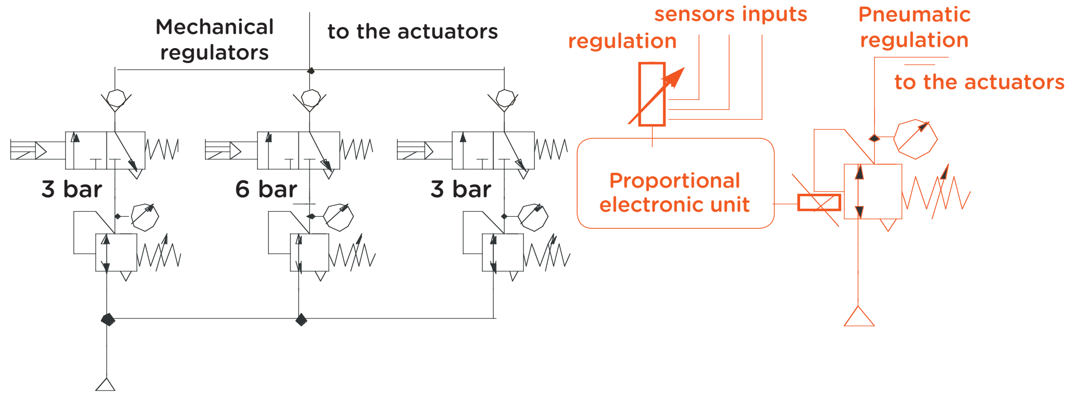


The diagram shows the assimilation to the line.

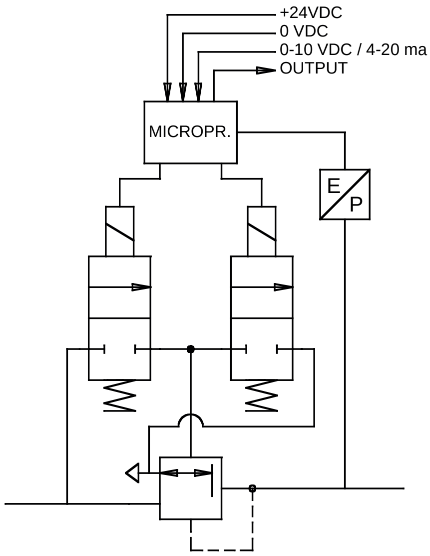
Its management can be made using an **open loop** or a **closed loop.**

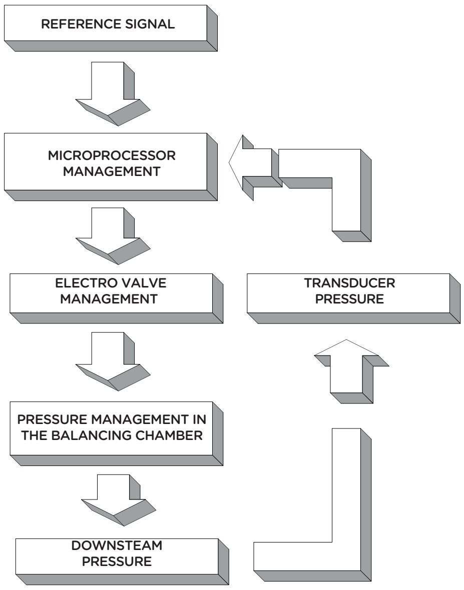


Example of pressure control
OPEN LOOP



In open loop management, the system does not allow corrections when external forces interfere with the performance of the final device managed by the proportional valve's exit signal, and this error is crawled until the interference disappears.
Closed loop management instead is featured by a feedback signal which continuously compares outlet value with the reference value, and in case of an error it proceeds to correct it. The figure in the following page shows the diagram for the operation of a proportional electronic regulator. The feedback is entrusted to an E/P electro-pneumatic transducer, which receives outlet pressure value and transforms it into an electric signal. The signal produced is sent to the microprocessor, which compares it with the signal modulated in inlet.



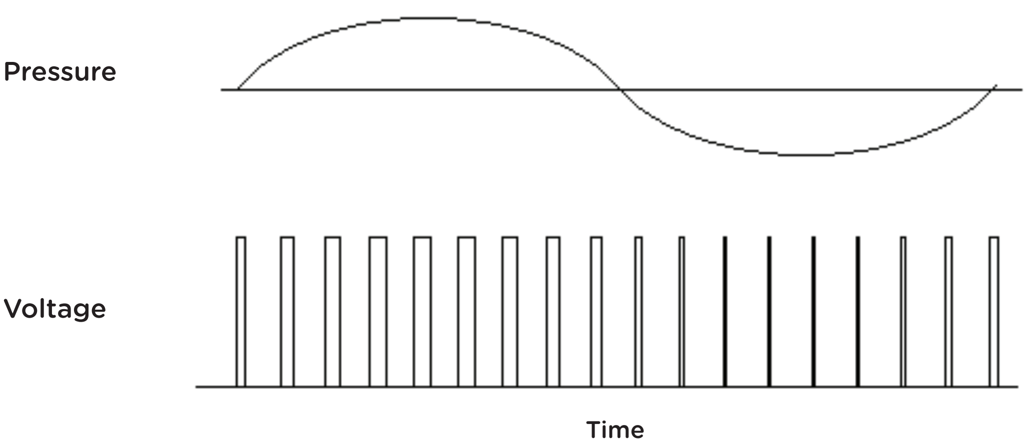


There are many application fields, independently from the device's operating principle.

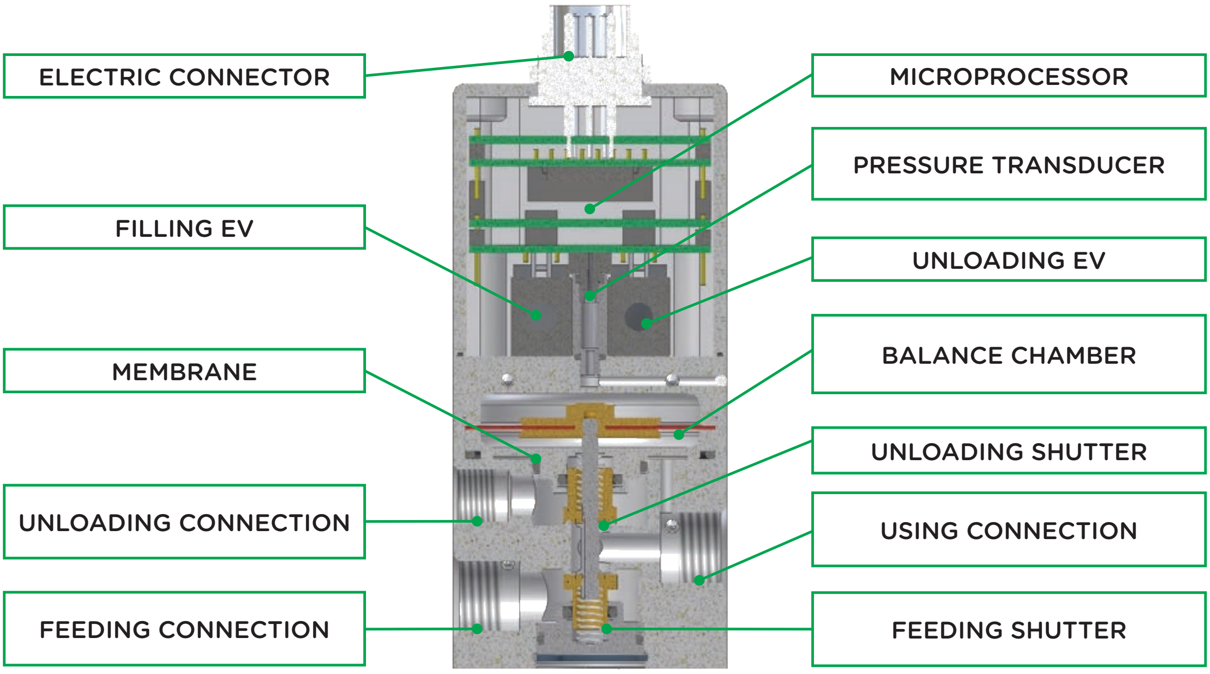
- Braking regulation on rotary or linear mechanisms
- Regulation of the tightening force of welding pliers
- Positioning of control valves
- Load balancing
- Control of the motion speed of pneumatic cylinders
- Painting robots, etc.
- Test stands and test equipment for sealing containers

The operating principle may be based on the balance and unbalance of two forces, which are a magnetic force and a return force proportional to outlet pressure.

Pulse Width Modulation



When the two forces are unbalanced, a pressure increase or reduction is required. Another principle is based on the port/nozzle system. Sending the control signal, a piezoelectric plate contorts blocking any nozzle that is losing compressed air. This increases the pressure in the chamber that presses on a membrane, which in its turn pushes the main shutter valve, exactly as is the case in the piloted pressure reducer. The system works only in face of air losses.
Another system uses the PWM (Pulse Width Modulation) control method, which consists in sending electric control signals in a different band frequency. These signals are sent to two electro valves that load or unload the piloting chamber of a precision pressure redgulator, as shown in the previously illustrated operating diagram.

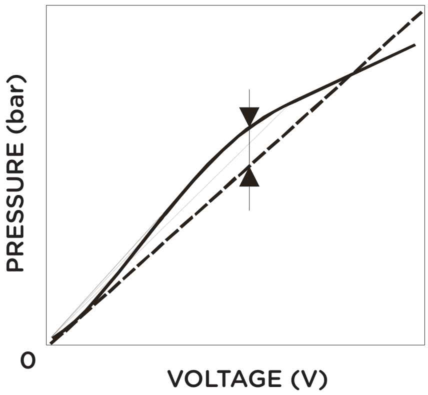


The width of the pilot electric signal shall be wider during the increase phase of outlet or unloading pressure, and it gradually decreases in proximity of reaching the balance until it interrupts itself. This allows the piloting electro valves to produce uniform strokes and reduce its own flow rate, avoiding fluctuations around the balance point. This is the most used system within that range of applications that do not require extreme precision, and it supplies optimal balance between performance and cost.
The features that mark a proportional electronic regulator may be summarized as:

- **Linearity**
- **Hysteresis**
- **Repeatability**
- **Sensitivity**

Linearity

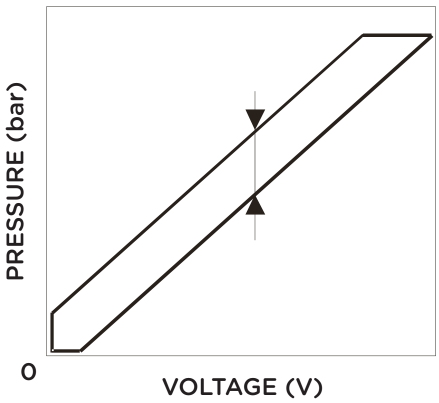
Linearity is the percentage value referred to full scale operation, and it defines the maximum possible deviation between the real running and the effective line.



If we define that the regulator has a maximum linearity lower than or equal to +/- 1% of the full scale (FS), and the full scale is equal to 10 bars, the maximum error shall be equal to +/- 0.1 bars.

Hysteresis

It defines the maximum deviation as a percentage, referred to the full scale, obtained on the outlet pressure with equal reference forward and downward values. It is caused by the frictions of the mechanic parts of the regulator.

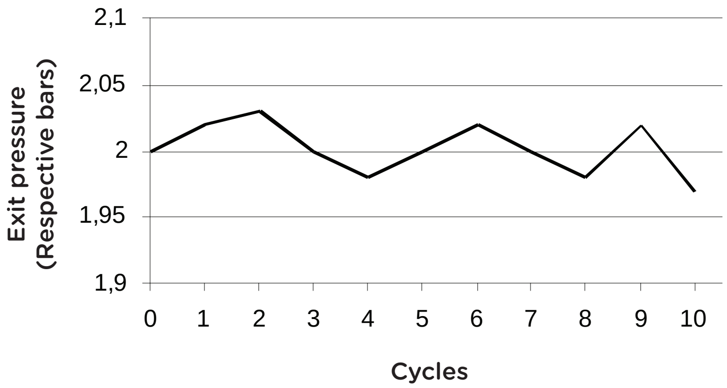


If we define that the regulator has a hysteresis lower than or equal to +/- 0.5% of its 10 bar full scale, we will obtain a maximum error equal of about +/- 0.05 bars.

Repeatability

It is also a percentage value referred to the full scale, and it defines the maximum error found on more readings carried out consecevly under the same operating condition.

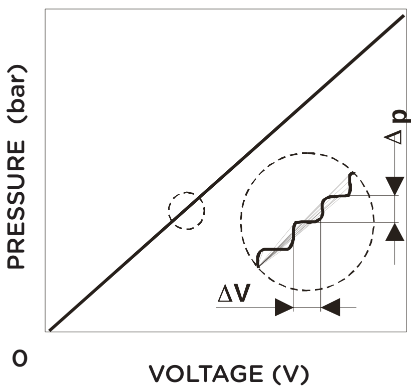
Errors are produced by hysteresis..



If the hysteresis is lower than or equal to +/- 0.5% with a 10 bar full scale, we know that the maximum error shall be about +/- 0.05 bars.

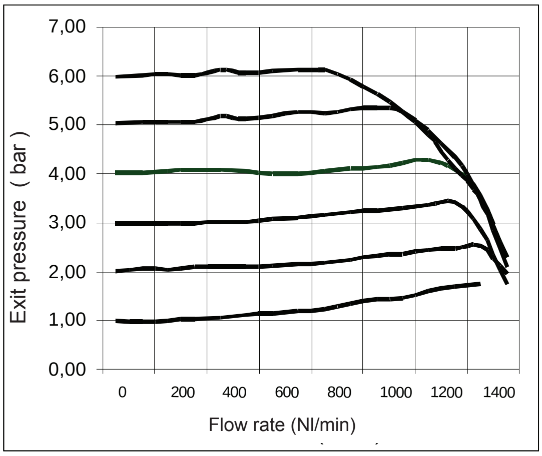
Sensitivity

It is the percentage value always referred to the full scale, which identifies the minimum variation of the reference signal to which a variation of the outlet pressure value corresponds.

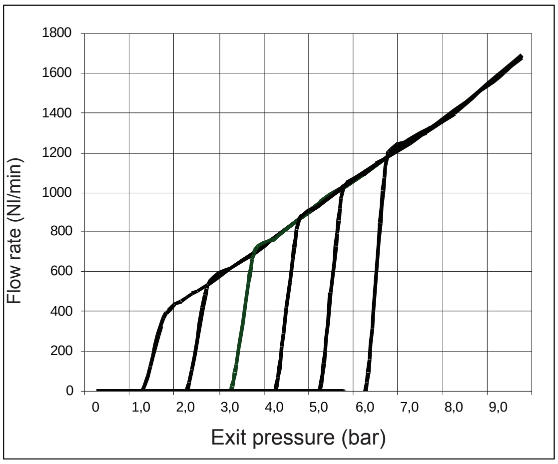


If a regulator with a 10 bar full scale has sensitivity lower than or equal to +/- 0.5%, we will have a variation of the downstream pressure for each variation of the reference signal higher than 0.05 Volts.
The electric features are then completed by the information described in the technical manuals. However, we must remember that reference signals may also be expressed as voltage, generally 0 – 10 volt DC and 4 – 20 mA for the version in current. When we carry out pneumatic connections, we must verify that there are no impurities in the tubes and that the compressed air is sufficiently dry. Any condensation could cause the device to operate incorrectly. Filter the air with a cartridge of at least 20 microns.

The minimum value of the reference signal does not correspond necessarily to an outlet pressure equal to zero. The deflection and the origin of the line may vary, as well as other operating parameters such the measurement unit of the pressure, the minimum pressure on which the device acts for its regulation, etc.
These operations are allowed acting in the set-up mode of the display or, if absent, the desired operating parameters may be set up directly by the manufacturer, and in this case, the user cannot modify it. The proportional electronic regulator, owing to its own features, must keep as much as possible a constant pressure, even when it has been set up with high downstream air requirements, obviously within the allowed values.



Feeding



Unloading

It must also be ready to respond in case of pressure restoring when the device is set-up for unloading. The exhaust has in fact a remarkable transiting section in order to allow this function.

Chapter 21

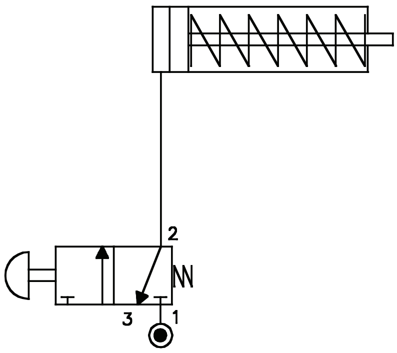
CIRCUIT METHODS

INTRODUCTION

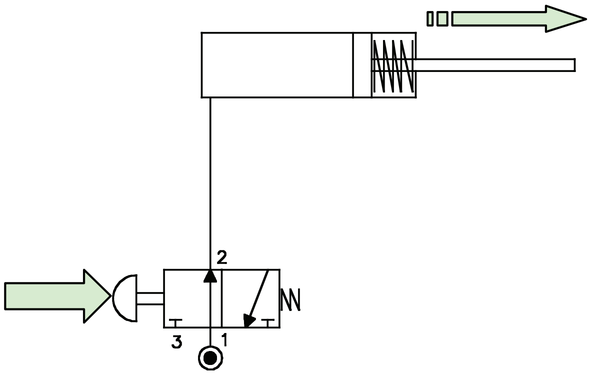
In this chapter we will introduce some pneumatic and electro-pneumatic circuits, starting from the simplest ones up to those that are relatively involved, which carry out movements with fixed automatic or semiautomatic cycles.
Machines with complex working cycles and with a high number of cylinders are governed by a PLC which allows flexible cycles, and which may be modified by simply changing the program. Complete pneumatic automations are less frequent; they are limited to very simple fixed cycles, or they are used in environments subject to explosion hazards.
In the graphic representation of pneumatic diagrams, the equipment, represented by symbols, are always drawn in the position in which they are while the machine is in standby. If a stroke limiter is activated or pressed in the described situation, it shall be represented in the diagram in that same condition. Instead, the standards establish that the symbol in electric diagrams must be represented in its resting position even if it is actually active when the machine is not operating.

21.1 ELEMENTARY CIRCUITS

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

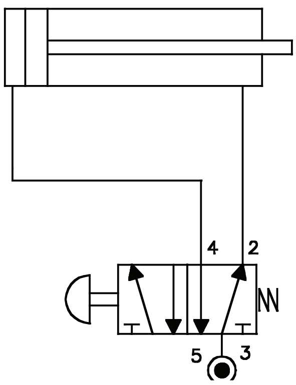


At resting position

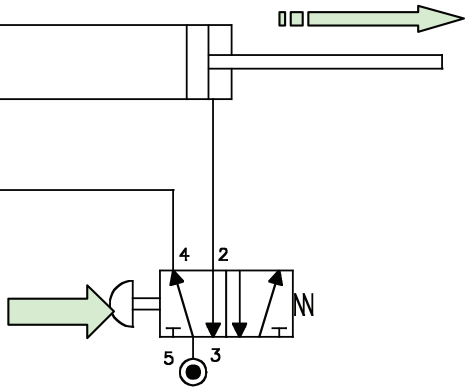


Active

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.



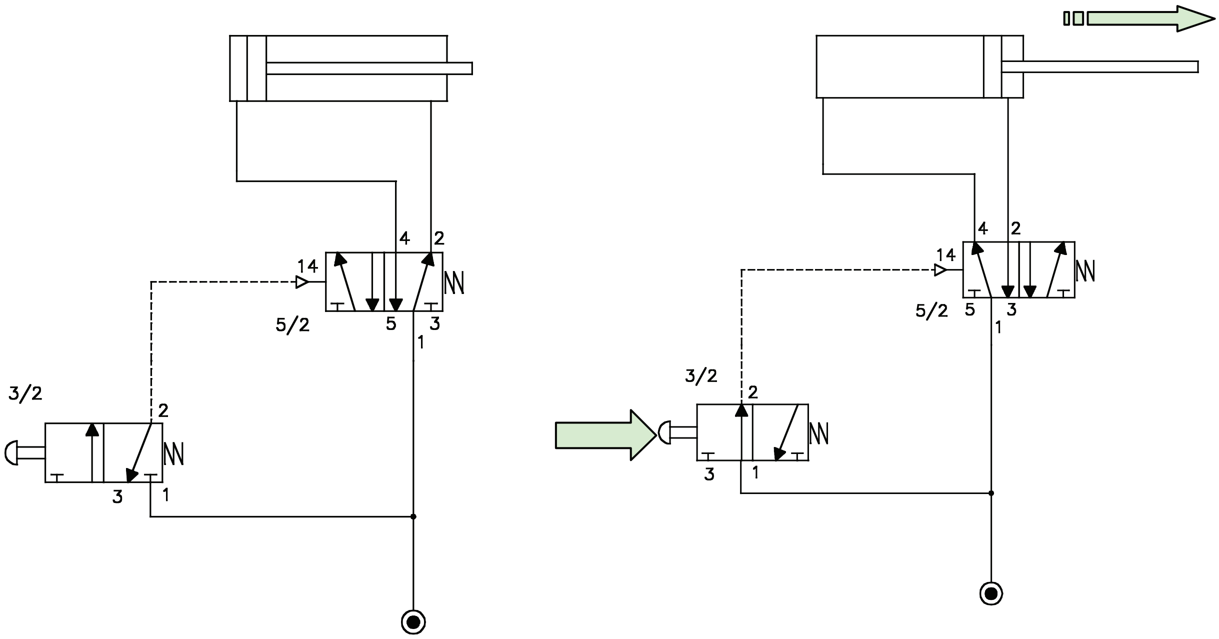
At resting position



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.

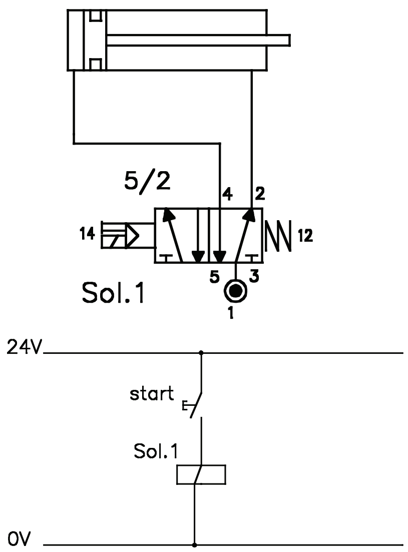
The correct valve to use is a 5/2, which also has a manual control. In its resting condition, port 1 is connected to outlet 2 which feeds the front chamber, while the back chamber is discharged by port 4 toward 5. Activating the valve, the two outlets as well as the exhausts are reversed and the rod comes out.
In the two illustrated situations, the cylinder rods remain in operating position until the valve's control signal continues. When the signal disappears, the rods return to their resting position because they are activated by monostable valves. The same operation may be carried out even if the cylinder is positioned in a not very accessible place, or if it has been sized in a way that direct activation is not possible. In this case, we carry out a remote control operation, using a small sized manual control valve with low actuating forces, and we pilot a pneumatic control valve near the cylinder or which has a size suitable for the cylinder to be served.
In this case, we carry out a remote control operation and, in case of piloting toward a larger valve, exaggerate the flow.



At resting position

Active

This direct function becomes indirect, but from the functional point of view, the operation carried out by the cylinder remains identical.
If we observe the position of the drawn valves, we can see that the control level is placed in a band at the bottom of the diagram and that the piloting lines are dotted lines. The ducts which carry the control signals are always distinguished in this way, while the main pressure lines are straight lines.



At resting position

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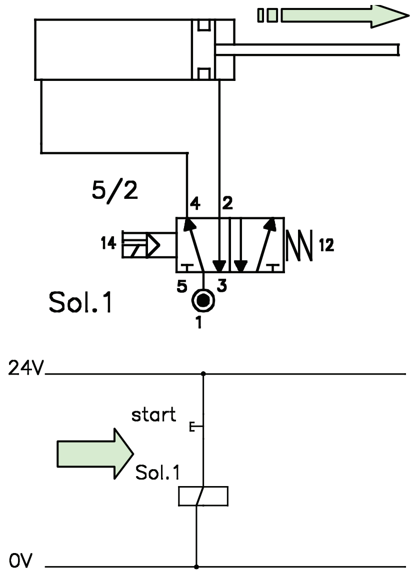
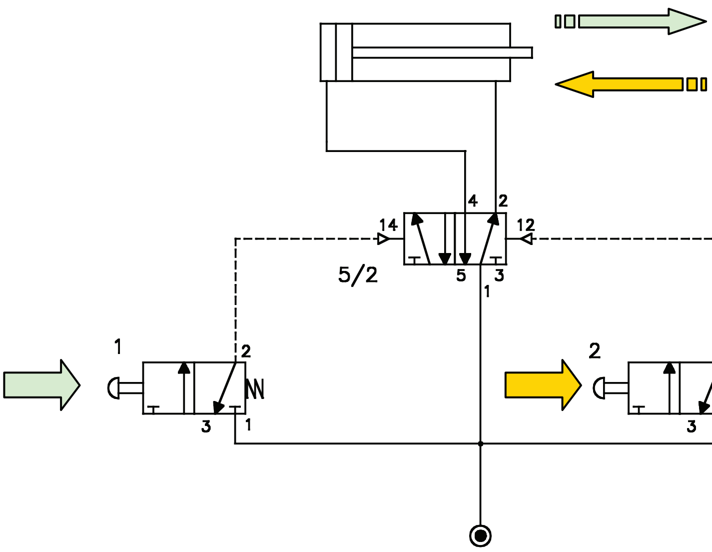


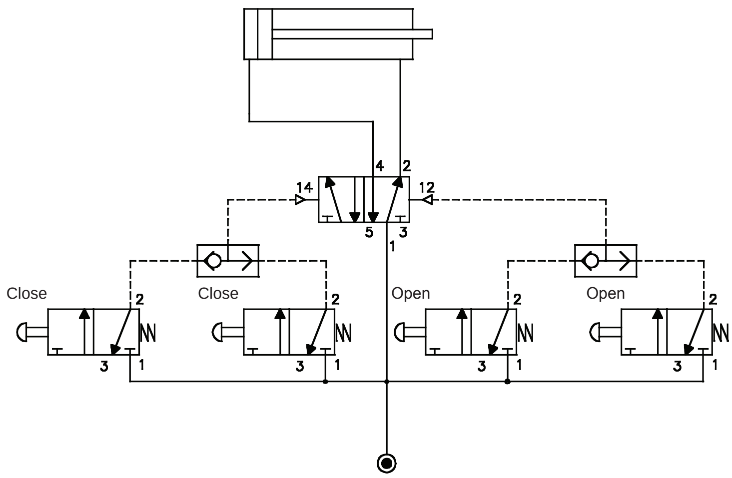
Active

The equivalent electro-pneumatic signal is illustrated in figure.
The pilot portion of the electro valve acts like a 3/2 valve which pilots the body of a 5/2 valve exaggerating the signal's flow rate.
A very common function is the "memory". This function allows us to keep the outlet signal of a bistable valve using an impulse control signal or one with a short duration. These circuits allow us to keep a cylinder in its desired position, even when the control signal disappears.

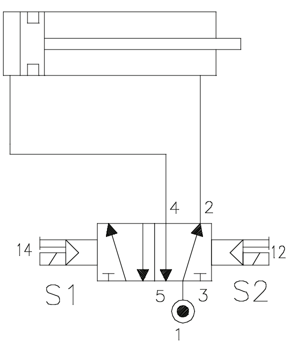


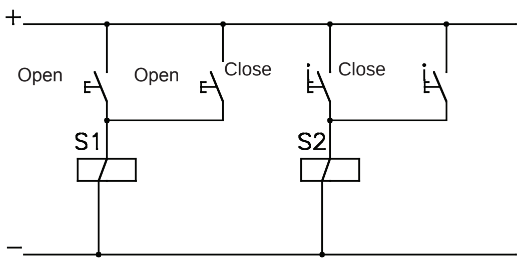
Activating the control valve of the cylinder with pulses emitted alternatively by the valves 1 and 2, we obtain the two fixed positions and we keep them during the entire time necessary, even without the presence of the respective signal. As already mentioned in the chapter "Valves", the presence of an opposite signal makes the control signal sent ineffective.

The equivalent electro-pneumatic signal includes a double-acting cylinder controlled by a 5/2 double-solenoid electro valve. Two electric buttons shall substitute the two 3/2 valves.
If the control points which sent the same order to the cylinder are more than one, the valves which send the same order in parallel must be necessarily connected.
The outlet signal of each of them shall be sent later to the inputs of a circuit selector switch that shall select one of the signals in order to control the cylinder's power valve. Using the selector switch prevents the compressed air from flowing directly from the outlet of one of the control valves toward the exhaust of the one placed in parallel.



Let's suppose that we must close and open a gateway from two different points.
As we can see in the diagram, the points "open" and "closed" are placed respectively on the right and on the left side, in order to help reading the diagram.
Actually, they are crossed at the two port slopes with an "open" and a "closed" position. In the electro-pneumatic version, the selector switch is not necessary because we do not have to worry about constraining the discharge in the presence of electric signals.





Electric buttons are simply connected in parallel.
Also, in this case the permanence of one among the controls constrains the opposite signal in both the pneumatic and electric versions.

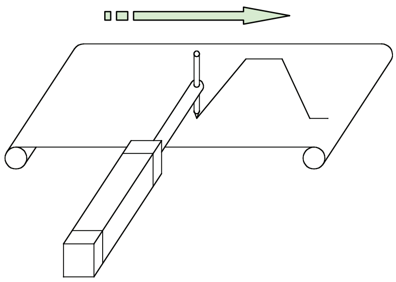
21.2 FLOW DIAGRAMS (DESCRIPTION OF THE SEQUENCE)

When one or more cylinders move according to a pre-ordered sequence, this must be described clearly and precisely.
In the first place, the retracted and extended rod positions of a cylinder shall be indicated with a minus sign and a plus sign.
Each cylinder shall be labeled with an alphabetical capital letter. If a cylinder has the label A, A+ shall indicate the extended rod position, and A- the retracted rod position. Each sensor of that cylinder shall have the same label but with small letter with the legend 0 if the sensor detects the minus position of the cylinder, and 1 if it detects the position plus. Therefore, in our case we will have a0 and a1.

The most simple sequence to be described is represented by the alternative automatic motion of a cylinder which, activated by the start-up control, begins the cycle which is interrupted by the stop signal. We can describe it literarily or represent it graphically.

A+/A- .... A+/A-

The literal description only shows the position in sequence of the cylinder, and it does not mark absolutely the start-up and stop signals, and where the stroke limit sensors which contribute to the automatic cycle are placed.
The graphic representation allows us to fill these gaps.
Let's imagine having a cylinder that contains a pen its rods tip. Under this pen a paper sheet slides, as shown in the figure.



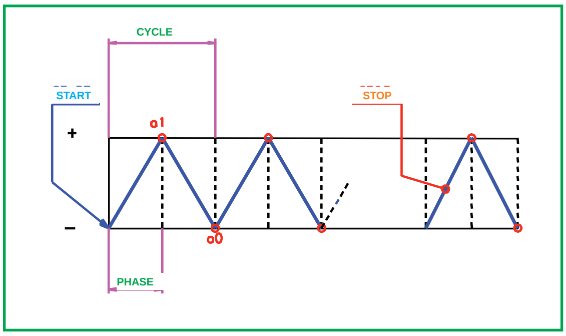
During the translation, this pen shall trace some horizontal lines on the sheet in the two standing positions + and -, and some angled lines during the movement between one of the two positions. The line's angle shall be more or less stressed according to the cylinder's actuating speed, which is not an interesting element when the diagram is designed. Instead, it shall be interesting when sizing the equipment referred to the same diagram.

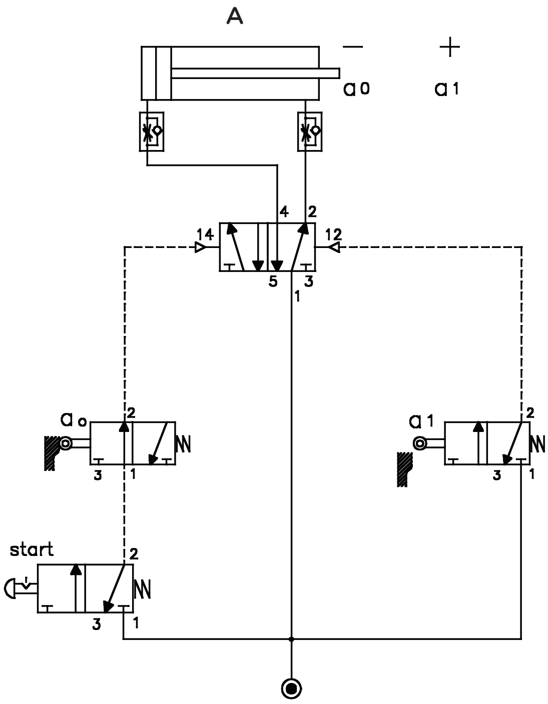
21.3 CIRCUITS FOR AUTOMATIC AND SEMIAUTOMATIC CYCLES

As we can see, each cycle consists in single phases (time) in which the representation of the cylinder's stroke (space) is developed. In this case, the cycle repeats itself for a

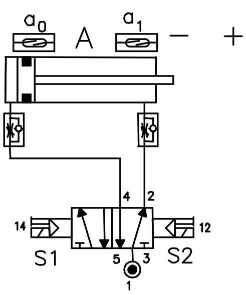
times until the stop action interrupts it.
Additionally, we can see that the late-cycle condition is set up with the rod in the – position. If the cylinder is running its stroke toward +, it shall complete the stroke and then shall stop at the stroke limit toward -. In fact, in the diagram the sensor of the stroke limiter a0 is connected in series to the start/stop valve in such a way that when the start signal is put in unloading, stop position, the last signal that reaches the cylinder's control valve is the one released by a1 which defines the cylinder A in position minus. Reading the diagram is very simple. When the start is activated, the start signal in A+ is sent by means of the activated stroke limiter a0 and, immediately later, a0 is released discharging the respective control duct. When the position + is reached, the stroke limiter a1 is activated, which orders cylinder A to return to position .

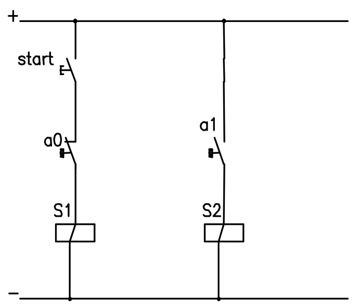
Cylinder A





The two positions keep alternating until the stop position is selected, obtaining the late-cycle with the mentioned conditions.



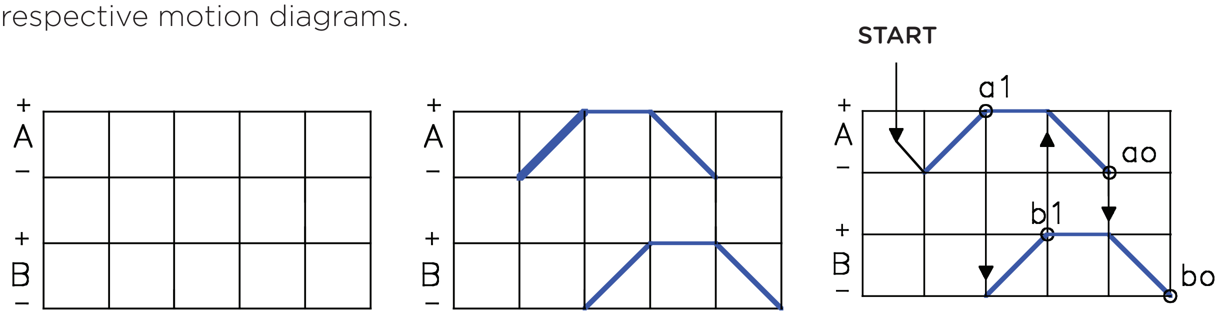


The electro-pneumatic version satisfies the same conditions and the same cycle.

Now let's try to draw the diagram of the motion and of the phases of two cylinders, A and B, which move according to the sequence:

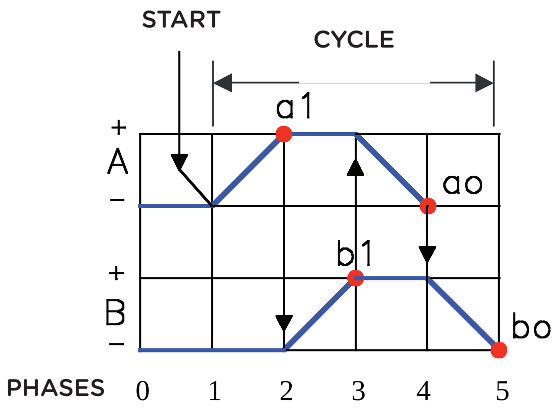
A+ / B+ / A- / B-

We should start designing two spaces in column and spaced each other (1), for their respective motion diagrams.



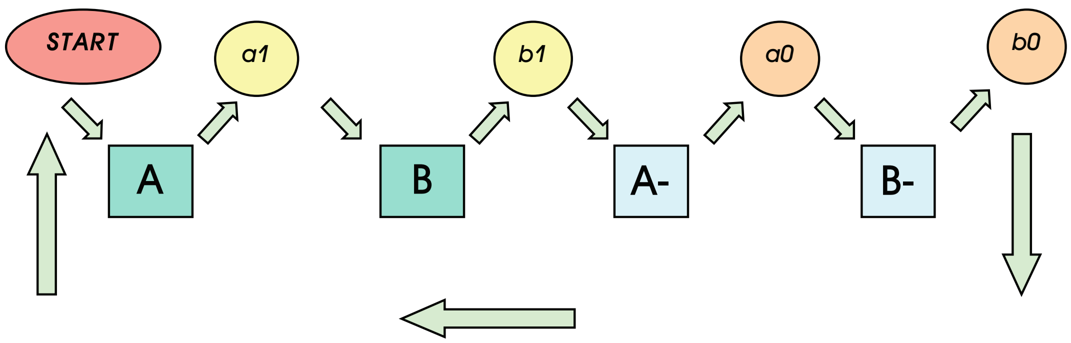
1 **2** **3**

Then we will describe the shown literal sequence (2) graphically, and finally we will insert the control signals which govern it (3).
The cycle in its different phases is thus defined.

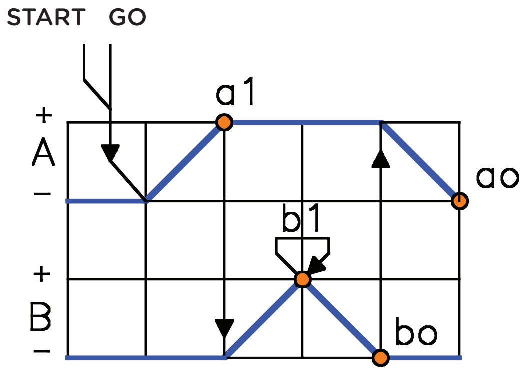


Please read:

- Phase 1: Start causes A+
- Phase 2: a_1 causes B+
- Phase 3: b_1 causes A-
- Phase 4: a_0 causes B-
- Phase 5: b_0 causes the cycle stop
  or its autimatic reset.



The controls are supplied by stroke limit valves activated directly by the cylinder's rods. With this system, we are sure that the planned sequence is strictly respected. The start-up, stop and emergency controls are sent by manual control valves. All controls issued by the mentioned valves are addressed toward the main distributors which activate the respective cylinders or the stop and emergency functions.
If we observe the sequence diagram described above, we can see that the signals released by the stroke limiters persist over time. For example, a1 is active from phase 2 to phase 3, b1 from phase 3 to phase 4, a0 from phase 4 to phase 5 and b0 from phase 5, which may coincide with phase 1 in case of automatic resetting, to phase 2.
In fact, the stroke limiter b0 is always activated when the cylinder B is in its minus position; therefore, it is also activated when the cycle is in phase 1 of start.
We can define these as **continuous signals** since they persist over time.



A+ / B+ / B- / A-

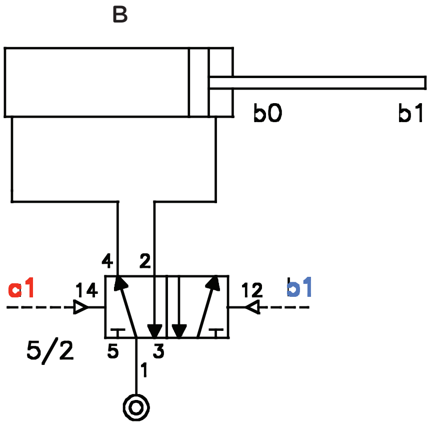
The sequence in figure shows that the signal released by b1 is an impulse signal because its stop line is minimized to a point.
We have found two types of signals in the two sequences:

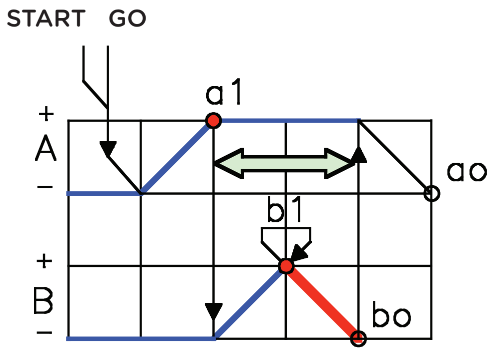
- **Impulse signals**
- **Continuous signals**

Continuous signals are divided respectively into:

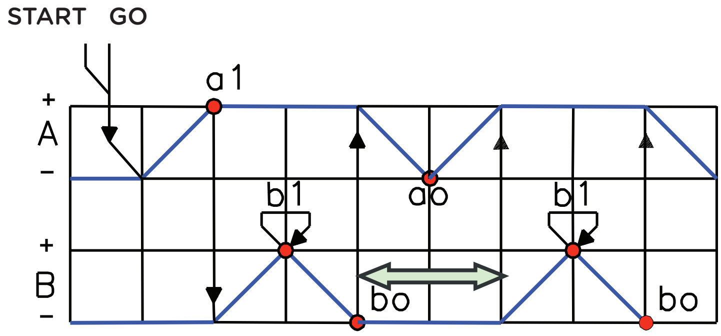
- **Simple continuous signals**
- **Blocking continuous signals**

Simple continuous signals persist over time and their presence does not cause any problems to the planned cycle development, even after having carried out the assigned task. Instead, blocking continuous signals, even if they persist over time, do not allow cycle development, blocking it in a phase with their presence.
Therefore, we must necessarily recognize them and limit their duration to make them simple continuous signals. If we observe the sequence described just now, when A assumes the position +, it activates a1 to control B+. When b1 acts, ordering position – of the cylinder B, the cycle stops because the signal released by b1 is opposed by the presence of a1.

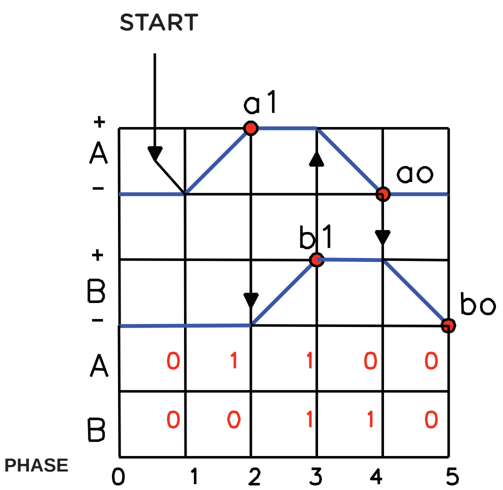




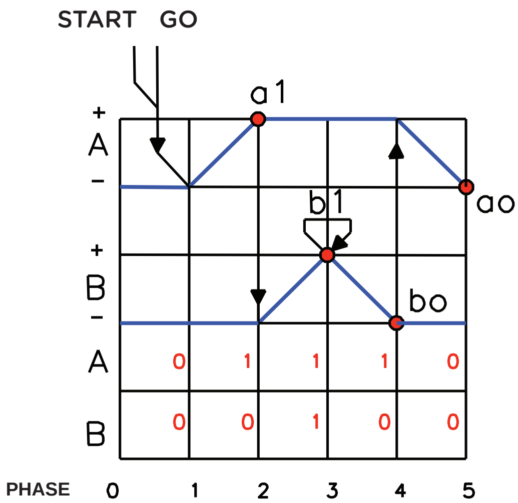
In the diagram in fact we can observe that a1 emits the signal of B+ even when b1 issues the order of B-. The signal a1 should be interrupted when b1 is activated.



If the cycle restarts automatically, we notice that the stroke limiter b0 acts exactly like a1 and it therefore shall also be a blocking signal.
Recognizing the blocking signals is not always simple, and to this purpose we will try using a method which makes this operation easier.
Let's examine the two cycles described until now.



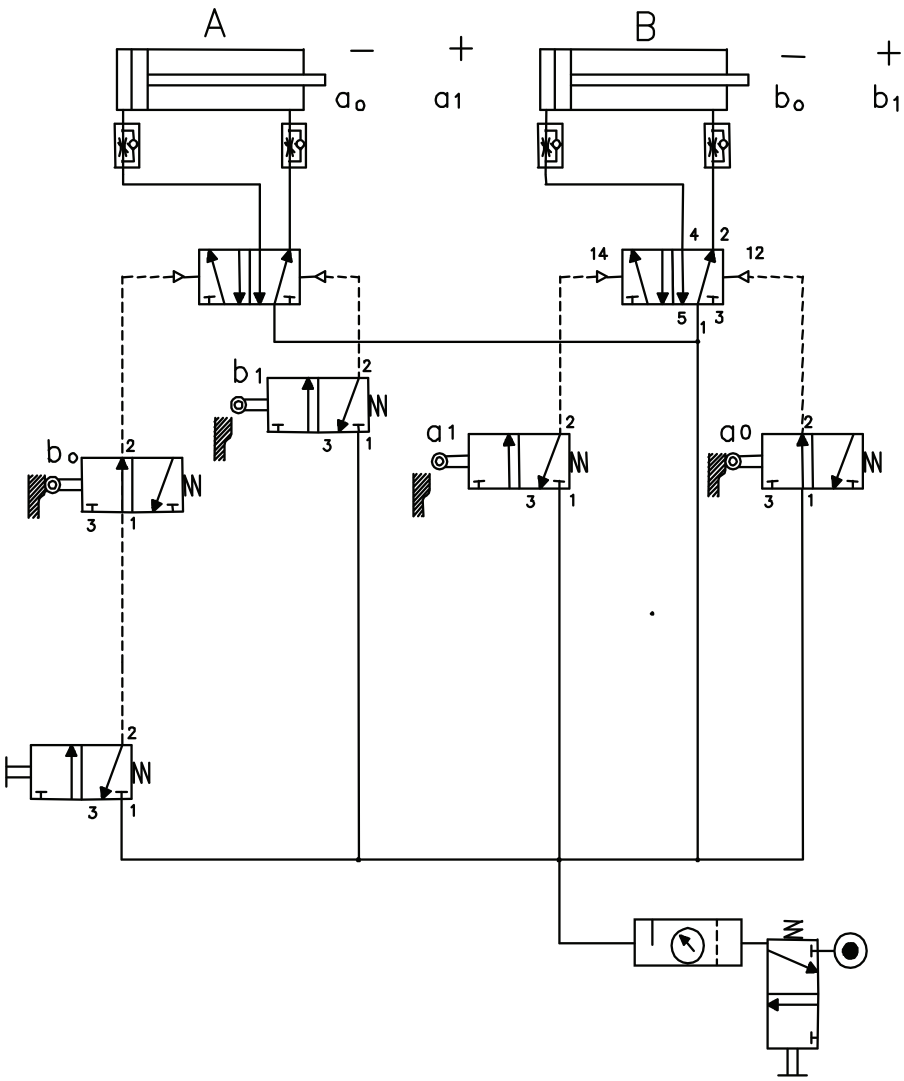
Cycle 1



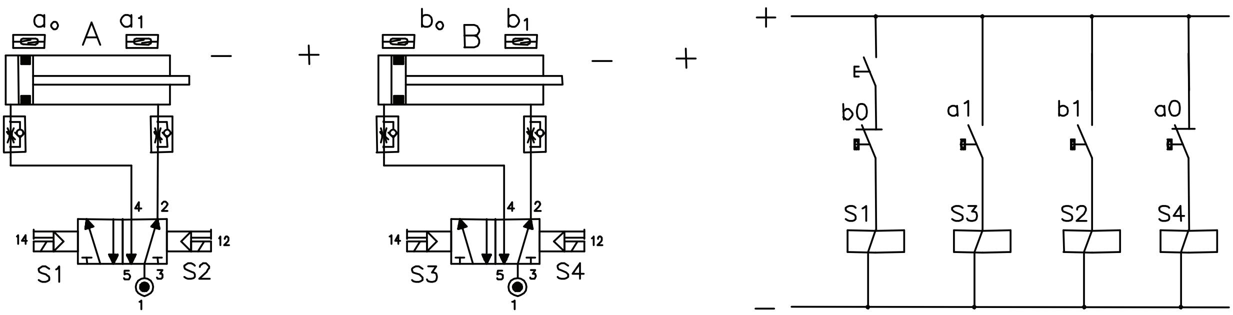
Cycle 2

For each phase of the cycle from 1 to 5 we assign the value zero to the respective cylinders A and B, if these are in their minus positions, and the value 1 when they are in their plus position.
In the cycle number 1, analyzing all the phases, we do not find identical combinations of 0 and 1, contrary to the cycle number 2, where in phase 2 and in phase 4 it repeats the same combination, in spite that the first one orders B+ to start and the second one, A- to start as well. As we have previously seen, the signals released by a1 and by b0 were recognized to be blocking signals. Therefore, when two combinations repeat themselves it means that the signals released by those stroke limiters are blocking signals.
Also, the combination 0/0 repeats itself, but, since the conditions of restart and late-cycle are coincident, we consider only one of the two combinations. We can eliminate the first or the last one indifferently.
For the cycle number 1, we can perform the diagram connecting all the feeders of its valves directly to the compressed air's source.

Cycle No. 1 A+ / B+ / A- / B-



Likewise, the electro-pneumatic version of the diagram is carried out very simply.



Cycle No. 2 must be solved differently in the presence of two blocking signals. Proceeding after trial runs should not be considered, because there is a very high risk of using more valves than those required.
In these cases, the design is supported by methods which allow reaching a safe and clean solution, with the necessary amount of valves and not more than required.
The simplest method among those used is the **cascade method**.
Starting from the literal description, the first step is to divide the described sequence into groups.

A+/ B+	/	B- / A-
Group 1		Group 2

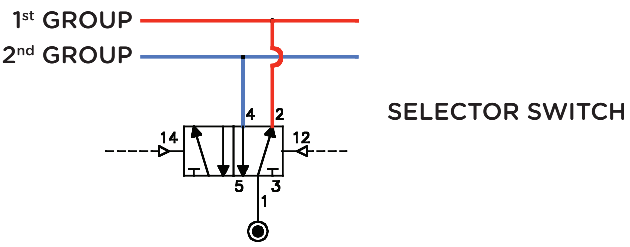
In our case, this division has produced only two groups, but in the event of sequences with three or four cylinders, the amount of produced groups may be higher.
An important aspect is that in the same group there are no opposed movements within the same cylinder.

A+ / A- / B+ / B-

This group division **must be not** carried out.

a_1 b_1		b_0 a_0
A+ / B+	**/**	**B- / A-**

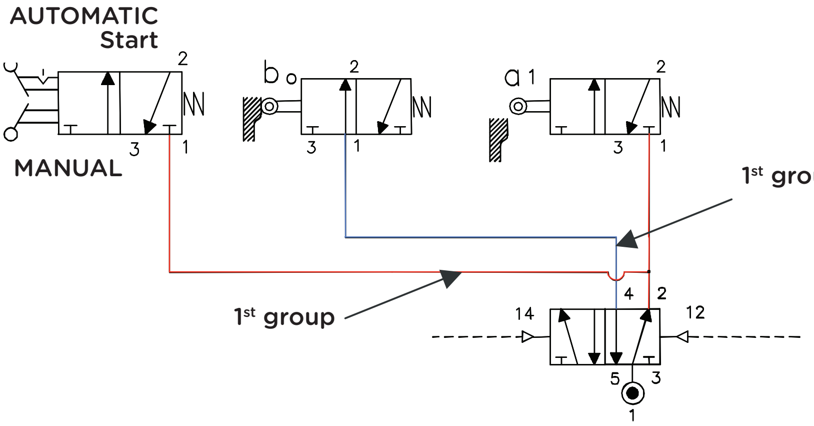
Each of the cylinders considered in the position + or – activates its own stroke limiter, as shown in the sequence described above.
Now we must design a 5/2 memory valve with pneumatic dual control.



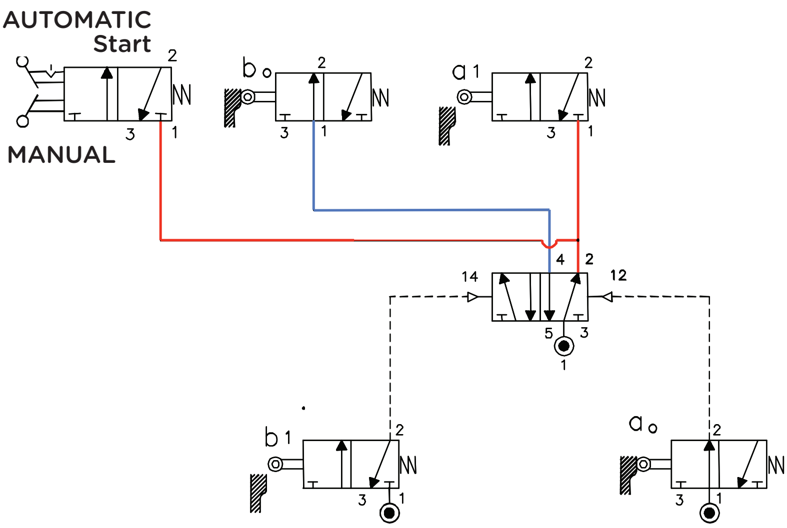
We will dedicate outlet 2 of the valve to the line of the first group, and exit 4 to the one of the second group, and we will call this valve "selector switch".
The next phase consists in connecting the stroke limiters to the two dedicated lines, according to this criterion:

- Connect the feeders (junction 1) of all the stroke limiters belonging to the cylinders of the first group except for the last one, to the line of the first group. In our case, we will connect a1, leaving the last b_1 free. Moreover, connect the feeder of the START valve to the same line.

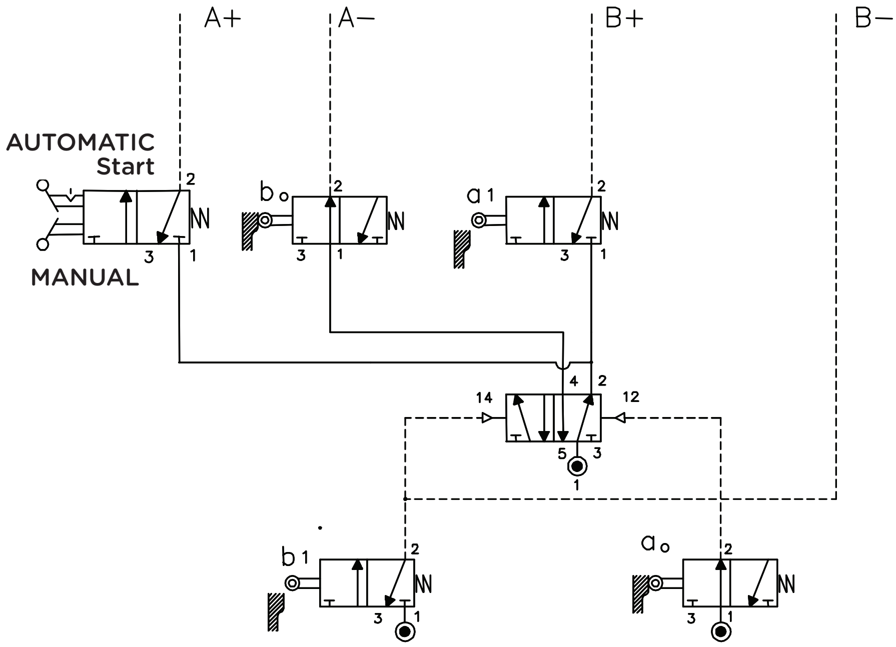
- Connect the feeders (junction 1) of all the stroke limiters belonging to the cylinders of the second group except for the last one, to the line of the second group.
We will connect b_0 leaving the last a_0 free.



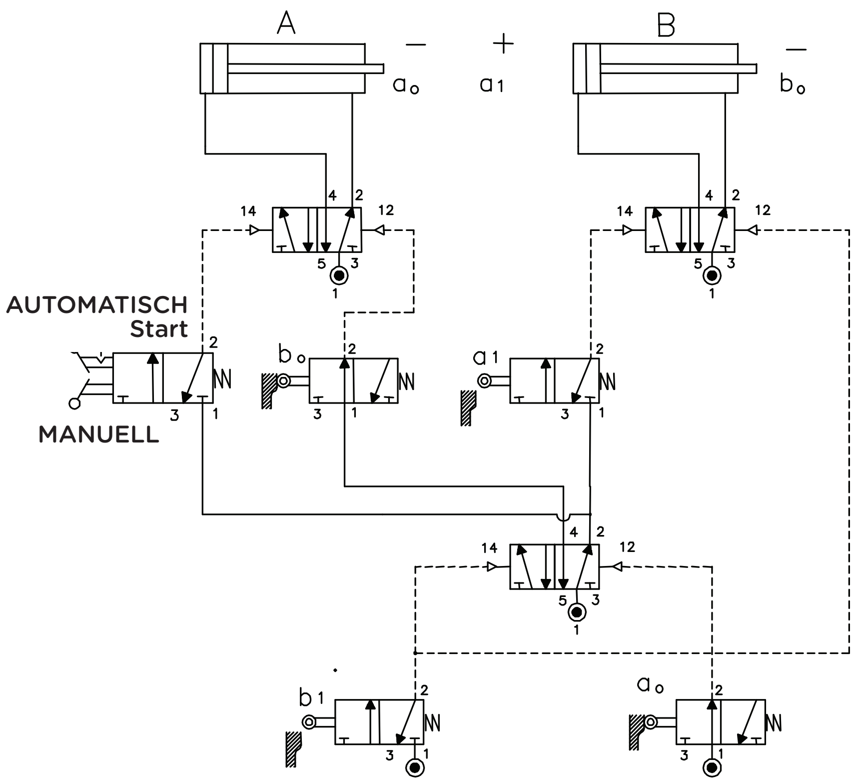
From this sequence, we can see that the stroke limiter b1 represents the last signal released in the first group, and we have recognized it to be an impulse signal. Therefore, we use it to activate the line of the second group, sending it to control 14 of the selector switch.
We have an identical situation with a_0 in the second group, in fact, it is the last signal released at the late-cycle and it shall be useful, after having sent its own signal to control 12 of the selector switch, to restore the starting conditions for a new cycle.

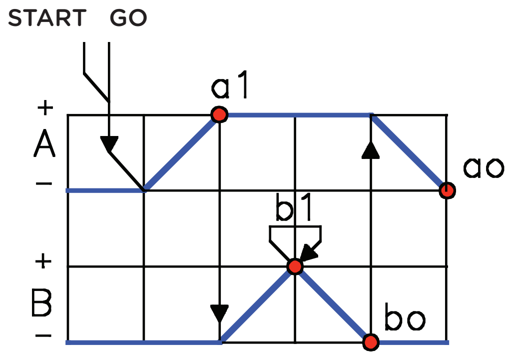


Now, all we can do is to send the signals coming from the outlets of the stroke limiters and from the START to the valves which control the cylinders.



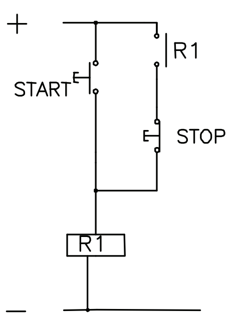
At this point, we can lay the complete diagram.



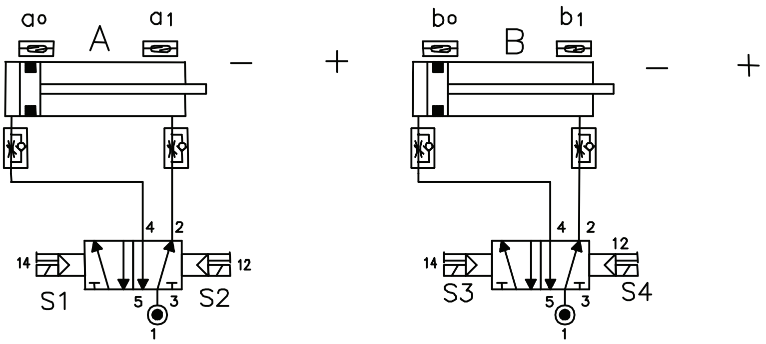


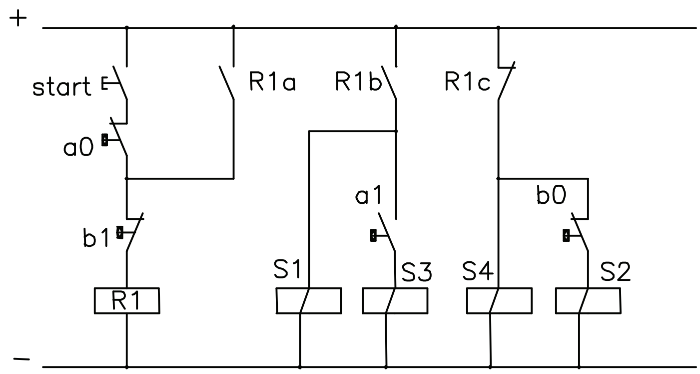
The cycle may function continuously if the control is set to “automatic” or, in case it is set to “manual”, it may carry out a single cycle.
In the electro-pneumatic version, a similar solution may be reached using a relay to operate as a memory.
To this purpose we remind the relay’s operation.

Relays are electro-magnetic devices that include an electro-magnet and a ferromagnetic anchor, which is attracted when an electric current is sent to the solenoid. The anchor is mechanically constrained to some contacts that are closed or opened by the anchor’s movement. Relays with changeover contacts like those shown in the figure are often used; there are relays which may have from one to four changeover switches. The self-holding function is used when an impulse electric signal is sent to the relay, which proceeds to self-feed even when there is no control signal.



The diagram shows the self-holding system. When the START is pressed, and when the coil of the relay R1 is energized, it actives an own contact parallel to the starting button and self-feeds. When START is released, its continuity is maintained by the contact. The contact of R1 shall fall when the STOP button is pressed.
With this system, we can use the relay's changeover switches and carry out the "selector switch" like in the pneumatic version. Signal selection shall be carried out by the same stroke limiters b_1 and a_0 that release an electric signal instead of a pneumatic signal.





The Start signal, by means of the series of a0 (N.O.) and b1 (N.C.), energizes the relay R1 which self-holds by means of contact R1a.
At the same time, it activates the changeover switches R1b and R1a. Solenoid S1 is energized and switches the respective electro valve which orders position + of the cylinder A. The stroke limiter a0 is released but relay R1 self-holds itself by means of contact R1a. At the end of its own stroke, cylinder A activates the stroke limiter a1, which, fed by the closed contact R1b, energizes solenoid S3. Cylinder B proceeds toward the own position +. Once it has reached its position, it activates the stroke limiter b1, which opens the contact and causes the fall of relay R1. The changeover switches R1b and R1a return to the resting position, and solenoid S4 orders cylinder B to return to position – in order to activate b0 again. The energized solenoid S2 shall make cylinder A to return to its position -.
If the Start is continues pressed, once a0 has been reactivated, the cycle restarts automatically. In the opposite case it stops and waits for a new Start order.

Therefore the performed cycle is:

A+ / B+ / B- / A-

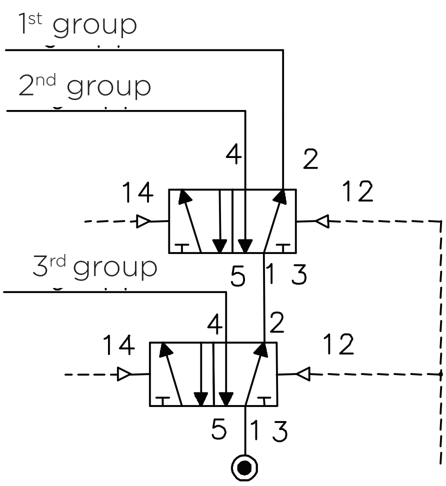
Drafting the diagram we have followed the cascade method. Sequences which include the movement of three or more cylinders are not carried out with completely pneumatic or electro-pneumatic automations using the relay method, but they are easily carried out using a PLC.
In order to understand better the means of "cascade", let's try to divide a sequence of three cylinders into groups.

A+ / B+ / B- / C+ / C- / A-

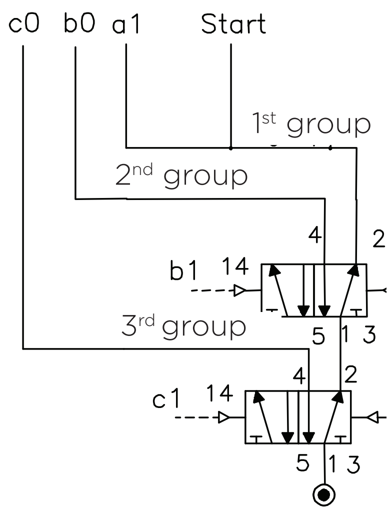
The division must be:

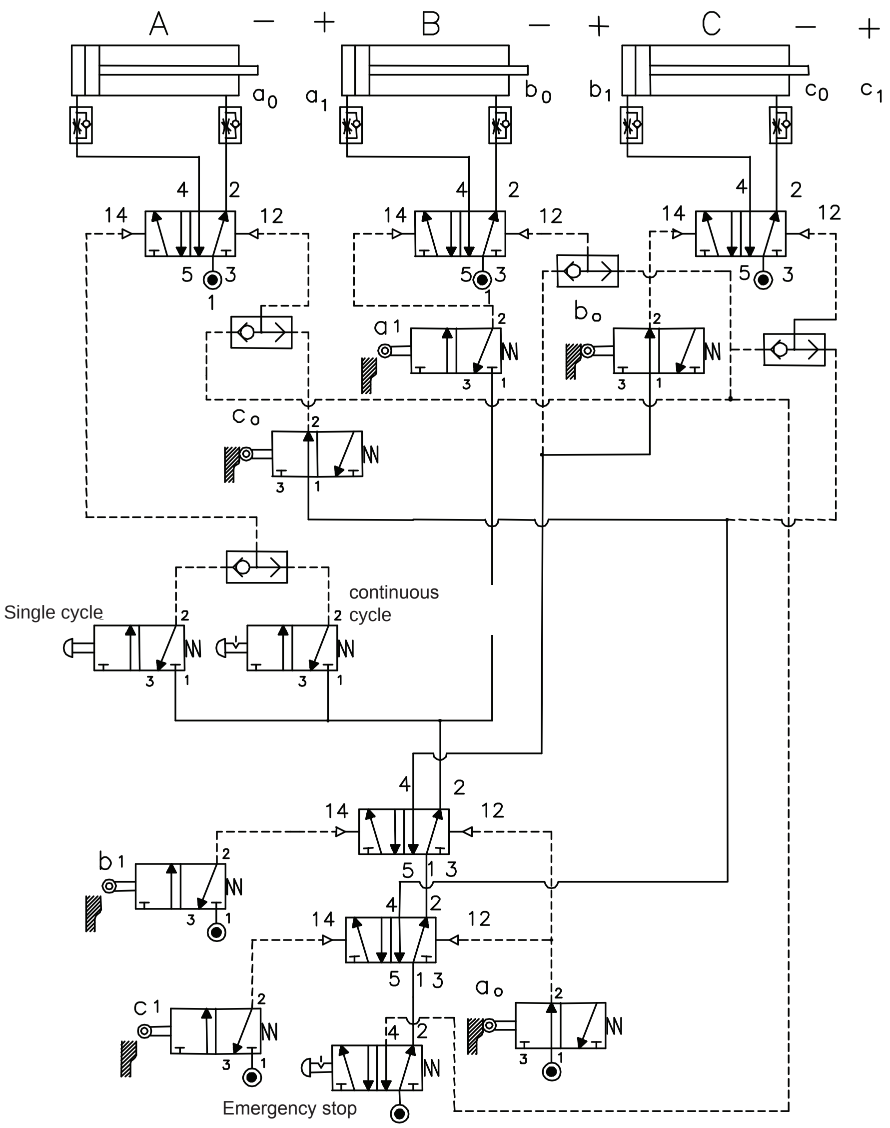
- 1st group: A+ / B+ Stroke limiter a_1 and b_1
- 2nd group : B- / C+ Stroke limiter b_0 and c_1
- 3rd group : C- / A- Stroke limiter c_0 and a_0

The stroke limiter b1 orders transit from the 1st to the 2nd group, c1 the transit from the 2nd to the 3rd and a0 the return from the 3rd to the 1st.
We will draw a first memory selector switch using outlet 2 as the line of the 1st group and outlet 4 as the line of the 2nd group, as we have done in the previous sequence. The line of the 3rd group remains to be defined. Let's draw a second 5/2 memory valve where we will dedicate outlet 4 to the line of the 3rd group, while we will send outlet 2 to the inlet 1 of the previous selector switch. The inlet 1 of the second valve is connected to the compressed air line directly.

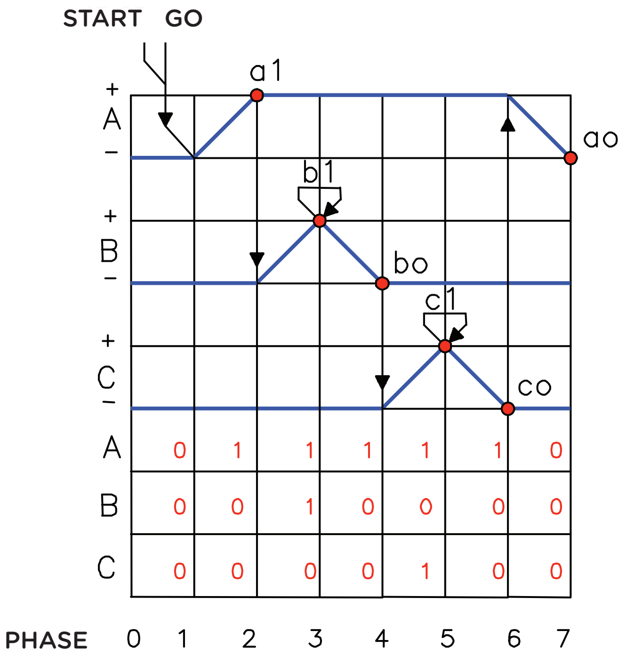


Let's connect all feeders (junction 1) of the stroke limiters respect to each group, except for the last one, and order the transits of the groups, as has been said.


c0
b0
a1
Start
1st group
2nd group
3rd group
b1
14
4
2
5
1
3
c1


A
B
C
−
+
a0
a1
b0
b1
c0
c1
14
12
4
2
5
3
1
Single cycle
continuous cycle
Emergency stop

The final draft must be carried out following the steps already described in the previous sequence. The circuit is then completed inserting the desired complementary functions, such as the buttons for single or continuous cycles and the emergency. The emergency, in this case, expects that all the cylinders in position + return simultaneously to the position - in any point of the cycle. We can see that the diagram is sufficiently complex for both drafting and interpretation, and therefore, it is convenient to solve the sequence using a programmable controller.



From the diagram of the cycle we can detect that phases 2, 4 and 6 have the same combination even if they issue different orders. In fact, the blocking signals are released by the three stroke limiters, which are fed by the two memory selector switches.

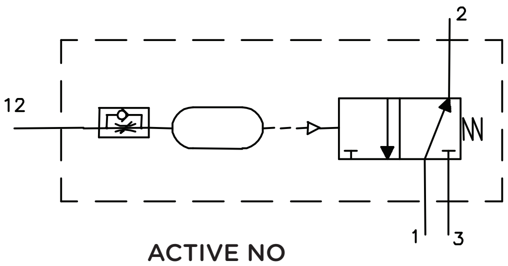
21.4 TIMERS

Timers are composite devices which are used for imposing a delay to an outlet signal with respect to the control signal. A delay in “energisation” or in “de-energisation” may be imposed to the outlet signal.

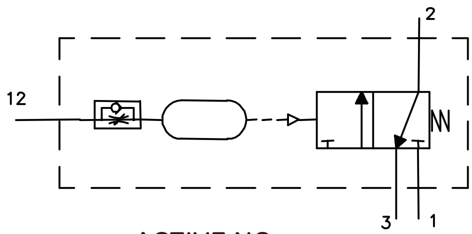
Delay in energisation

An outlet signal, which may be positive (in pressure), or negative (in unload), is released after a period of time imposed according to the arrival of the control signal. Usually, the device is constituted by a 3/2 NC valve for the positive signal or NA for the negative signal, with pneumatic control and a spring return.

A small tank with a flow regulating valve is connected to the control junction according to the following diagram.

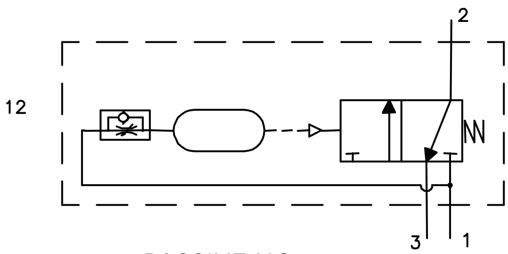


ACTIVE NO



ACTIVE NC

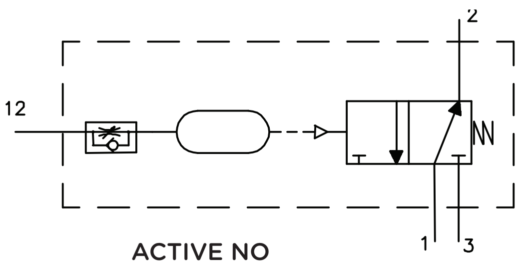
The unidirectional flow regulating valve works in the direction of the tank where, due to the throttle, the threshold pressure for switching the 3/2 valve shall be created after a certain time. At this point, the pneumatic signal appears at outlet 2 in case of a NC function or disappears in case of a NO function. Control 12 may come from outside and in this case we can speak of active control, or it may be connected directly with the feeding way 1, and in this case we can speak of passive control.



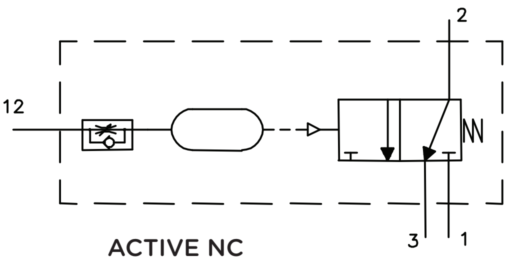
PASSIVE NC

Delay in de-energisation

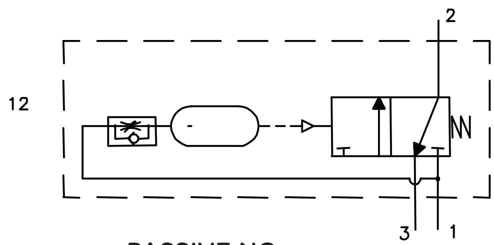
For the delay in de-energisation, the flow regulator works in the opposite direction, therefore control 12 is immediately activated to switching the 3/2 valve. When this disappears, the volume of the tank unloads, controlled by the throttle, delaying reaching the de-energisation threshold value of the 3/2 valve.
The outlet signal disappears after a certain time in the NC case, or appears again in the NO case. Also, in this version the active and passive functions are expected.



ACTIVE NO



ACTIVE NC



PASSIVE NC

Timers are not always exact when used in repeated process because their operation depends on the availability of air which is not always constant. But they are sufficient to perform in most applications.

21.5 LOGIC FUNCTIONS

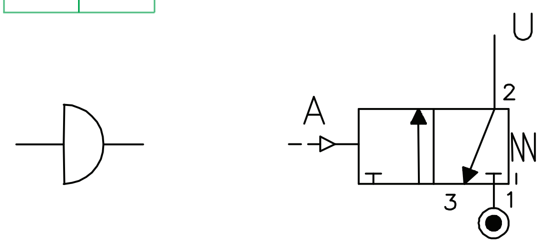
Pneumatic systems work in most cases as digital systems, and the operation of their components is defined by the signal's status. Its presence shall be defined simply with 1 and its absence with 0. Signals have no need to be modulated, providing that they stay within the operating levels of each component.
The pressure present in a piping system produces status 1 and its absence, status 0, as well as the activation of a stroke limiter produces status 1 and its deactivation, status 0. Therefore, only two statuses are possible, 1 or 0. Data processing is carried out according to the binary logic rules. The basic logic functions are: affirmation (YES function), negation (NOT function), sum logic gate (OR function) and product logic gate (AND function).

YES Function

Affirmation is the operation with which signal is repeated in identical way. If the control signal is 0, the outlet is 0, if the control is 1, the outlet is 1.
Generally, outlets are amplified with respect to the control signal or inlet.

A	U
0	0
1	1

U = A

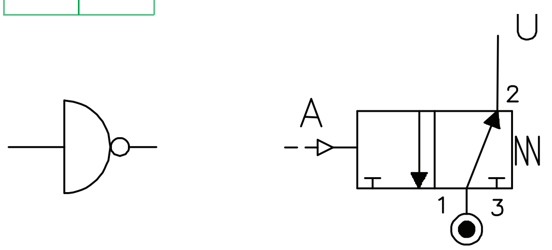


NOT function

In negation, the control signal is transformed into its complementary signal, if the inlet is 0, the outlet is 1, if the inlet is 1 the outlet is 0.

A	U
0	1
1	0

$U = \bar{A}$



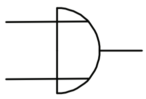
The negation of the control signal A causes outlet U.

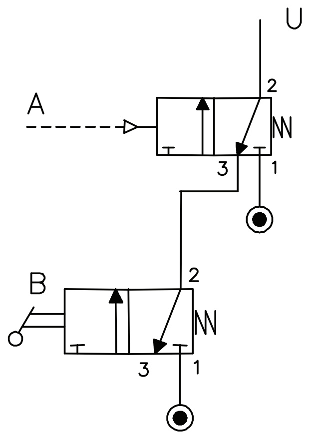
OR function

The logic sum of two or more binary signals produces the value 1 if at least one of the signals is equal to 1 and the value 0 if all the signals are equal to 0.
Having two generic control signals A and B, they shall produce an exit U with the presence of one of them or of all the two controls.

A	B	U
0	0	0
0	1	1
1	0	1
1	1	1

A + B = U





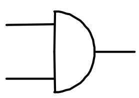
If for example we want to send an alarm signal toward a central unit from different sensors distributed along the machine, the intervention of only one of them shall be enough to stop the machine. Sensors are connected in sum logic, which of them may send the alarm signal.

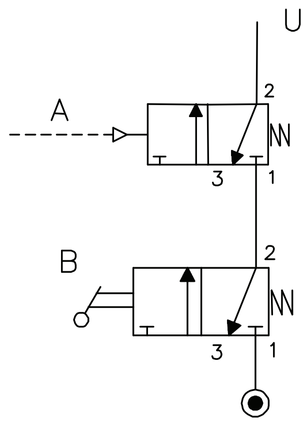
AND function

The product logic is the function that assumes value 1 if all inlets or controls are 1. In the opposite case it is 0. In presence of two generic controls A and B, we shall have outlet U when both A and B are present.

A	B	U
0	0	0
0	1	1
1	0	1
1	1	1

A x B = U





A control or confirmation system may be carried out by a logic product.
If all parameters referred to the control of a product or to the confirmation of an operation are active, then the outlet shall be 1.
It is the acceptance signal of the product or to start the operation. The AND function has been carried out.

Chapter 22

COMPLEMENTARY CIRCUITS

22.1 COMPLEMENTARY CIRCUITS

After having drafted the diagram where the sequence is carried out correctly, it must be completed inserting all those functions inherent to consensus, safety and emergency situations. There are composite devices that perform safety tasks, as for example the two-hand control which meets the European EN 574 standard, or devices with fluctuating circuits, pulse generators, etc. All these things are carried out in order to guarantee the operator's safety, even in the event of accidental movements of any cylinder. The designer must consider all needs required for correct operation of the system and act consequently, inserting the start, stop and emergency signals according to the established criterions.

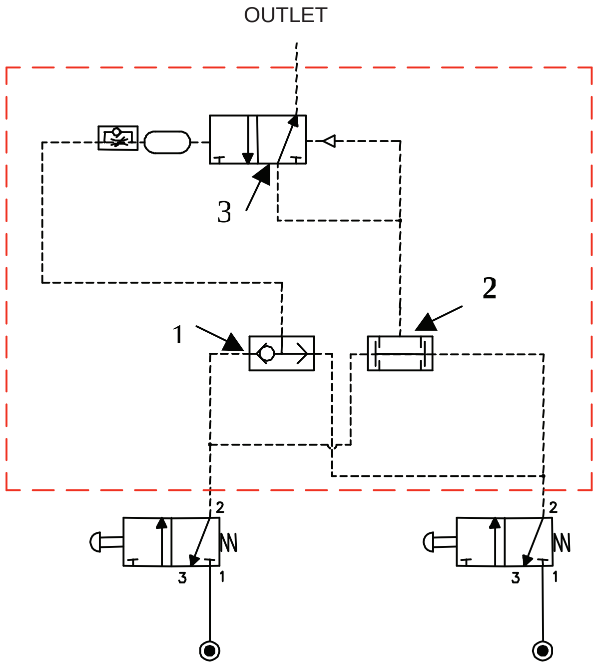
Two-hand safety control

Two-hand safety control is used in those situations where there is a risk of accident. In fact its purpose is to prevent that the operator's hand may be placed in the working area, making him use both his hands to emit the cycle's start signal. The two-hand starter must respect specific requirements in order to meet the standards and to be classified as an approved "safety device".

These requirements must be:

- Non repeatability
- Simultaneity

First of all, the two starting buttons must be placed in such a way that they may not be activated using only one hand, the signals must be emitted in parallel within about 0.5 seconds, and release of one of the two buttons deactivates the outlet signal. If the released button is pressed again there shall be no exit. Release of both buttons and their next simultaneous pressing is necessary in order to produce a new exit signal.
The operating principle is based on the processing of the two inlet signals released by the two buttons by means of a proper circuit, as shown in the following diagram.
Generally, the device includes a composite device and, if approved, it must be accompanied by the respective documents that certify its homologation.
However its components may be assembled in order to arrange the circuit with the abovementioned features.

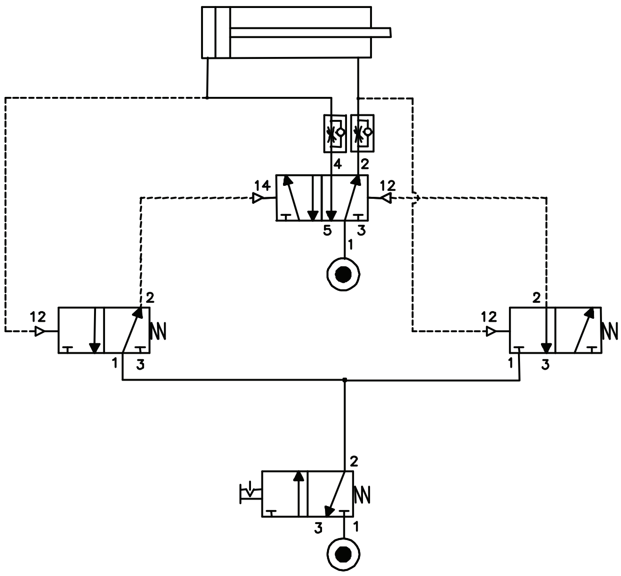


The two inlets are the signals released by the two buttons, which are carried to the OR 1 and of the AND 2 inlet ports. If the signals released by the buttons are distant from each other in time, the outlet of OR 1 is immediately sent to the control of valve 3 by means of the delay function, constituted by the unidirectional flow regulating valve and by the small tank connected to it in series. If this signal comes first, it establishes itself on the one released by the AND 2 and switches valve 3, closing the way which is normally opened. The outlet signal is not active because there was no simultaneity. In case there was simultaneity, outlet of AND 2 should come first to confirm the designed position, since it was free of timers.

The signal should have reached the outlet by means of the way normally opened of valve 3. If one of the two buttons is released, there should be no exit signal of AND 2 and immediately the outlet of OR 1 should prevail on its side of control, referred to valve 3 closing its open way.
Even if the released button should be pressed immediately, the situation at valve 3 should not change, and the outlet of the device should continue to be null. Both buttons must be released and pressed again at the same time in order to obtain a new exit signal.

Fluctuating system

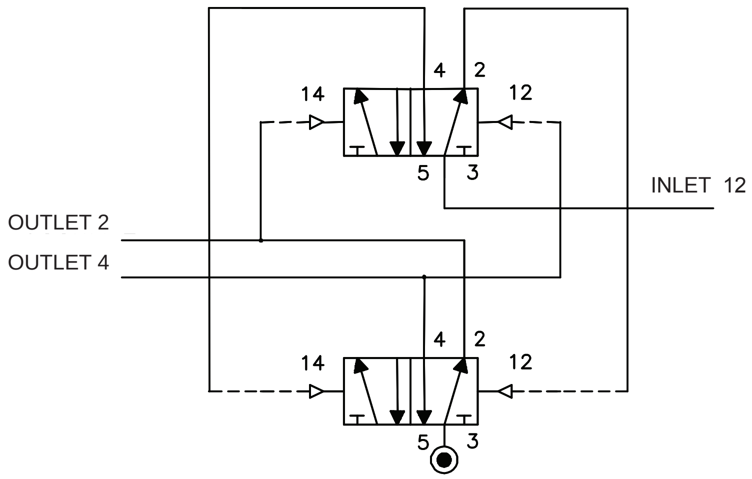
The fluctuating function allows connecting the device to a cylinder directly, and once that it all is fed with compressed air the cylinder begins to perform forward and backward strokes until the feeding is disconnected. Also, in this case the device may be a dedicated composite device, or it may be made up by the devices connected to each other, as shown in the following diagram.



The fluctuation is performed with the support of virtual stroke limiters carried out with two NOT functions.

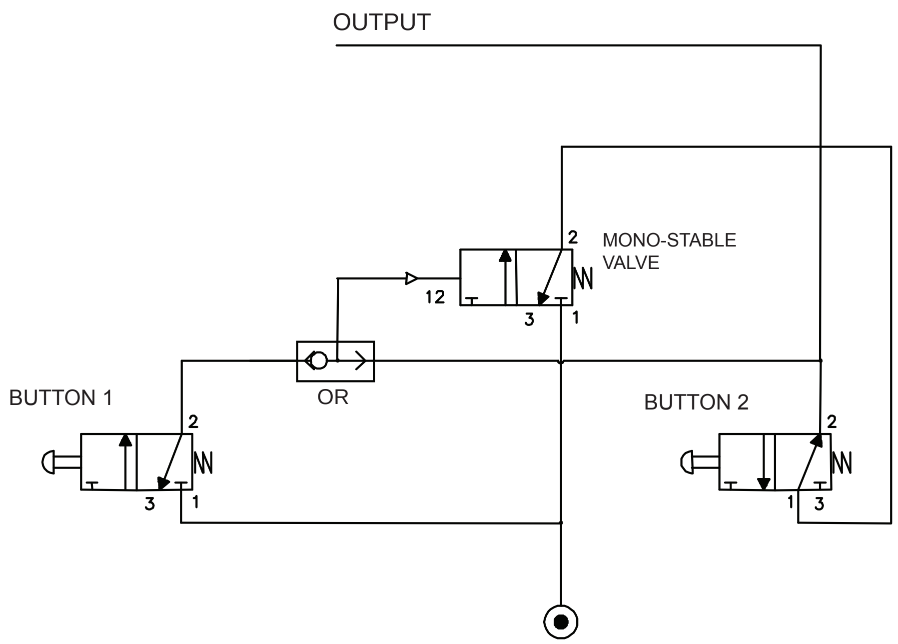
Flip Flop circuit

Flip flop circuits consist in two 5/2 valves properly to connected each other. At each inlet pulse, the outlet switches from 2 to 4 and vice versa.



Self-hold circuit

Producing a self-hold situation is possible in a completely pneumatic circuit, as we have seen doing with the relay. In this way, a valve which would generally be used as monostable is transformed into a memory.



Button 1, when pressed, by means of OR, orders the monostable valve to switch, and its outlet self-feeds its own control 12 carrying out the self-hold procedure, by means of the normally opened button 2.
The discharge remains present even if button 1 is released. The outlet closes only if the button 2 is pressed, which unloads control 12 of the monostable valve by means of OR.

Chapter 23

USE AND MAINTENANCE

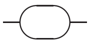
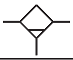
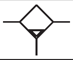
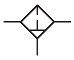
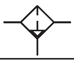
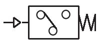
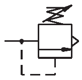
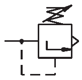
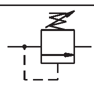
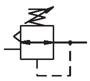
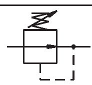
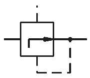
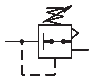
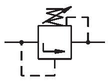
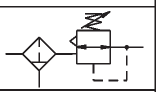
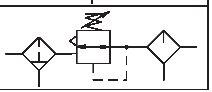
Pneumatic valves and cylinders are simple and solid devices and their proper use allows long operation over time.
Therefore, the first regulations to be respected are that the air must be well processed and lubricated, whenever necessary.
During cylinders' assembly, precise alignment with respect to the applied load must be verified, in order to avoid radial loads that, as we know well, cause rod flexion damages in guide bushings and gaskets.
Furthermore, in addition to long strokes avoid very high speeds and excessive loads.
Finally, evaluate carefully the conditions of use from both the mechanical and environmental points of view (aggressive chemicals, high temperatures, dust and humidity) and consequently choose the most suitable type in order to keep maintenance to a minimum.
When we must intervene on a cylinder, we must proceed to disassemble it and to clean each part impeccably using a non-aggressive degreasing agent and a further jet of compressed air in order to complete its cleaning.
Avoid the use of frayed rags which may leave fibers on the cleaned parts. After having controlled and substituted any worn out and damaged parts, reassemble the cylinder and lubricate it with a proper grease.
We must pay particular attention to control sliding surfaces, ports and rod, which must be in good conditions.
All damaged surfaces will cause early wear of the gaskets.

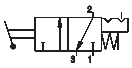
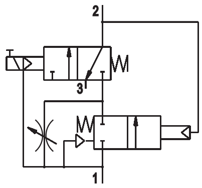
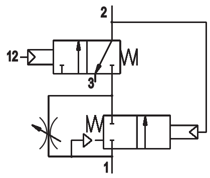
Check that the clearance between the bushing and the rod must not exceed 0.2 mm. A larger movement will cause damages to the rod's sealing gasket.
In order to block the heads, tighten up the clamping screws, cross screwed with the advised tightening moment after having aligned the heads correctly.
For cylinders with screwed heads (micro-cylinders) the already described cleaning and control rules are valid, but we must proceed to disassemble the front head heating the part up to about 100 °C in order to neutralize the bonding effect of the screw-lock. Before reassembling the cylinder, proceed to clean the head threads and ports thoroughly, and use screw-locks in order to avoid accidental unscrewing after having aligned the two feeding ports.
Usually, the manufacturers' catalogs provide exploded views with the necessary references to order the most common spare parts which usually come in repair kits. Use proper tools to carry out the described operations in order to not damage the replaced gaskets accidentally.
The mentioned rules and methods are also valid as guidelines for different kinds of cylinders such as cylinders, rodless cylinders, rotary cylinders, etc., paying attention to the requirements which these cylinders must meet.
In wire cylinders, for example, verify appropriate wire tensioning and, in rodless cylinders, the internal sealing strap.
Due to the particular features of the mentioned cylinders, sometimes maintenance is carried out better by the original manufacturer's staff, which has all the required information and tools.
Likewise, all fixing accessories must be controlled, in particular the fluctuating ones which are constituted by pin/hole couplings.
In these cases, we must proceed to verify the movement between pin and bushings and proceed to lubricate the parts correctly and regularly.
It is worth remembering that pneumatic parts are designed to be used with compressed air at a maximum value equal to 10 bars, and the pressure normally used for this equipment must be around 5 to 6 bars, which must be controlled by a pressure regulator in order to stabilize its value.
The operating pressure field for every unit is described in the respective sections of the manufacturers' catalogs.
The main source of damages caused to valves must be attributed to the presence of foreign bodies in the system that cause damages to the sealing gaskets. To this purpose, using proper filters capable of retaining liquid and solid impurities is essential.
The filter must be discharged frequently with the simple operation of opening an unloading tap, carried out manually by the maintenance personnel.
If its mounting position is uncomfortable or difficult to reach, it may be useful to install an automatic discharge filter.
Many times lubrication is required, and to this purpose the lubricator is introduced into the feeding line in an amount of atomized oil that is to be directly proportional to the flow. The lubricant must be suitably regulated because too much or either poor lubrication may cause the equipment to malfunction.
A method to verify if lubrication to a specific valve has been performed properly is to place a clean white rag near its exhaust.
After some activation, if the valve has been lubricated properly, there shall be a soft spot on the rag.

Use compatible oil with the materials employed by the gaskets' manufacturers. In this regards, the catalogs describe the features of the oils to be used.
To clean the FRL groups use water-based detergents only. Solvents will damage the cups of filters and lubricants irreversibly.
The distributing valves have an average lifetime of about 20 million cycles and they may function with lubricated air, except for any different indications to the contrary.
Commonly, there are replacement kits available for maintenance operations.
During the disassembling phase, pay attention to the sequence of the gaskets and spacers which have to be assembled in their identical positions.
Clean the sludge deposits or impurities accumulated on the internal walls accurately using water-soluble detergents or non-aggressive degreasing agents.
Avoid solvents and abrasive materials.
Solvents may damage the gaskets and abrasive materials' sealing surfaces. For electro valves, in addition to cleaning the contacts, it will be useful to control the wearing out conditions of the sealing rubbers of the pilot valve's mobile nucleus, and verify the status of its top surface that must appear free of traces on its sides.
Clean air the feeding ducts with a jet of compressed from the body valve toward the electric pilot valve.
Generally, pneumatic equipment may operate within a temperature range going from -20°C to +80°C.
Its use with temperatures under +2°C needs that the used compressed air has to be dried with special equipment.
The purpose is to avoid ice accumulation due to condensation.
Before proceeding to disassemble a valve, the maintenance man must control other possible causes which may determine its bad operation.
For example, air leakage from a valve exhaust may be caused by a leak from one chamber to another one of the controlled cylinder due to a piston gasket failure. Disconnect the tube connecting the valve and the cylinder and verify if there is a leak.
If there is a leak, we must open the cylinder and substitute the piston's gasket, if there is not a leak, we must open the valve and substitute the leaking gasket.

PNEUMATIC "AIR TREATMENT" SYMBOLS

AIR SERVICE UNITS

Air treatment mechanisms	
Pneumatic accumulator (capacity)	
Automatic drain air	
Automatic drain air	
Lubricator	
Air filter	
Filter - with manual drain	
Filter - with automatic drain	
Pressure control valves	
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	

Other mechanisms	
Pressure gauge	
Shut-off valve	
Progressive start-up valve With Electric control	
Progressive start-up valve With Pneumatic control	

PNEUMATIC "VALVE AND ELECTRO VALVE" SYMBOLS

- **main connections**:
- supply connection identified with number 1
- consumption connection identified with number 2 and 4
- exhaust connection identified with number 3 and 5
- **Pilot connections**:
- repositioning connection on 2/2 & 3/2 ways valves identified with number 10
- switching connection on 2/2 & 3/2 ways valves and repositioning connection on 5/2 & 5/3 ways valves identified with number 12
- switching connection on 5/2 & 5/3 ways valve identified with number 14

Switching : is the process that changes the state of a valve from rest position to actuated position and is achieved by means of a mechanical, pneumatic or electric signal
Repositioning: is the process that changes the valve state from actuated back to rest position and is achieved by means of an external mechanical (spring), pneumatic (differential) or electric signal
Ways: indicated the number of connections on the valve body and on the pneumatic diagram
Positions: indicates the number of positions achieved by the valve and corresponds to the number of squares on the pneumatic simple.
Function: indicates the valve working diagram at rest condition and corresponds to the right square in the pneumatic scheme.

Valves symbols

Way	Pos.	Function	Symbol
2	2	Normally closed	
2	2	Normally open	
3	2	Normally closed	
3	2	Normally open	
5	2	Separated exhaust connections	
5	3	Closed centres	
5	3	Open centres	
5	3	Pressured centres	

Switching and Repositioning

Mechanical	Pneumatics
Plunger	Pneumatic
Sensitive plunger	Pneumatic -return to center
Roller	Pneumatic - depressurised
Unidirectional roller	Differential (pneumatic spring)
Sensitive roller	Differential external pilot
Pedal	Sensitive differential
Pedal - spring return	**Electrical**
Push Button	Solenoid
Sensitive push button	Bistable solenoid
Push button - two positions-.	Solenoid (internal pilot)
Lever	Solenoid (external pilot)
Lever - spring to center	Solenoid - spring to center
Sensitive lever	Solenoid with suppl. pilot
Two position mechanical stop	
Three position mechanical stop	
Spring	

Complementary valves

Throttle valve	Silencer
Bidirectional flow regulator	Non-return valve without spring
Unidirectional flow regulator	Non-return valve with spring
Quick exhaust valve	Non-return valve controlled during closing
Shuttle valve	Non-return valve controlled during opening

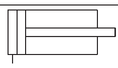
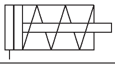
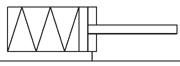
Piping and connections

Pressure line	One-way rotating intake
Control line	Three-way rotating intake
Exhaust line	Closed air intake
Flexible line	Air intake with connection
Electric line	Quick coupling connection without non-return valve
Piping connections	Quick coupling connection with non-return valve
Piping intersection	Air exhaust unthreaded connection
Main air connection	Air exhaust threaded connection

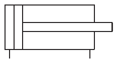
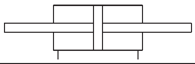
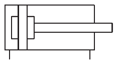
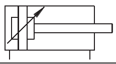
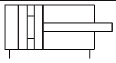
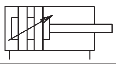
PNEUMATIC “CYLINDER” SYMBOLS

CYLINDERS

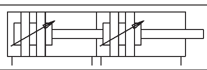
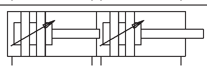
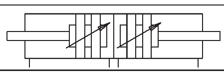
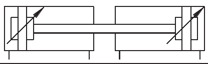
Single acting cylinders

with external return	
with spring return	
	

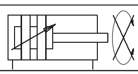
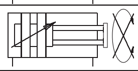
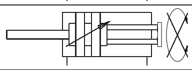
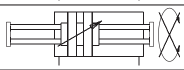
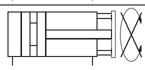
Double acting cylinders

Standard rod	
Double rod (push/pull version)	
With non adjustable cushioning	
With adjustable cushioning	
With magnetic piston	
With magnetic piston with adjustable cushioning	

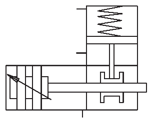
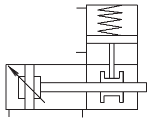
Tandem cylinders

In tandem, common rod	
In tandem, independant rods	
In tandem, opposite rods	
Opposed, common rod	

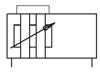
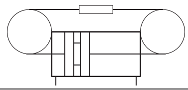
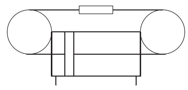
Non rotating cylinders

Standard rod / double acting	
Twin rod / double acting	
Twin rod / double acting push/pull rod	
Push/pull twin rod double acting	
Guided compact cylinders	

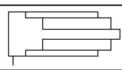
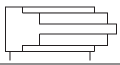
Cylinders for piston rod lock

With magnetic piston with adjustable cushioning	
With non magnetic piston with adjustable cushioning	

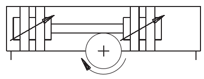
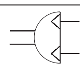
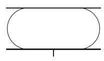
Rodless cylinders

With magnetic piston With adjustable cushioning	
Cable cylinders with magnetic piston	
Cable cylinders with non magnetic piston	

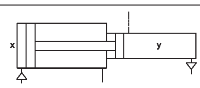
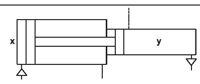
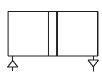
Telescopic cylinders

Single acting	
Double acting	

Various cylinders

Rotating cylinders	
Rotating cylinder	
Bellows cylinder	

Pressure boosters

Air-Air intensifier	
Air-oil intensifier	
Hydropneumatic accumulator	

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