CAMOZZI COMPETENCE CENTRE

CAMOZZI

Automation

PNEUMATIC AUTOMATION
FROM BASIC PRINCIPLES TO PRACTICAL TECHNIQUES

Published by

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CAMOZZI COMPETENCE CENTRE

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Automation

PNEUMATIC AUTOMATION
FROM BASIC PRINCIPLES TO PRACTICAL TECHNIQUES

THE IMPORTANCE OF EDUCATION IN PNEUMATICS

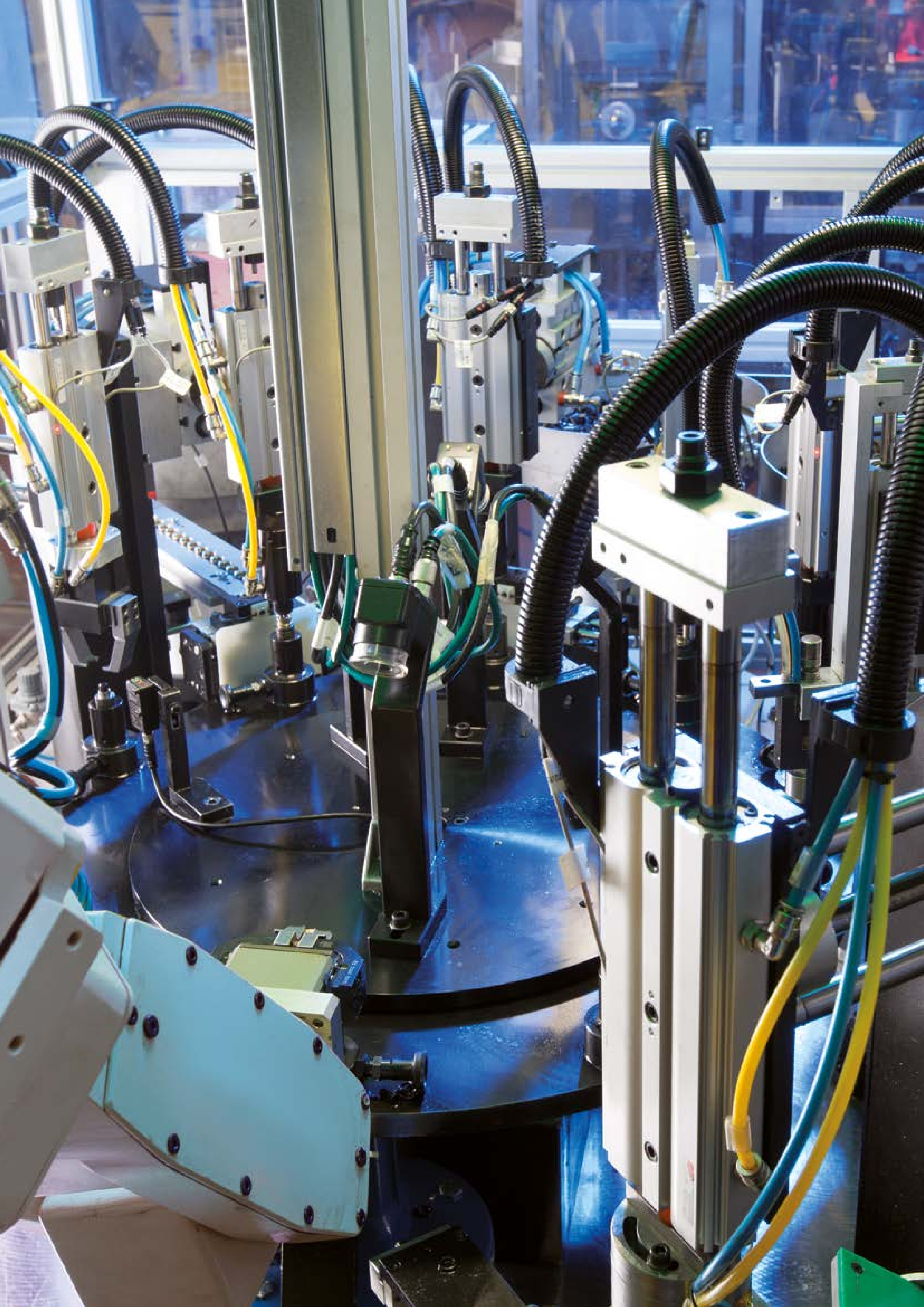
Camozzi Competence Centre
Expertise and passion

Providing innovative high quality solutions to clients, offering efficiency, quality and reliability with components adapted to the requirements of each sector, thereby resulting in maximum added value in terms of both performance and customer benefit, this has always been the mission of Camozzi.

The growing demand for ever more complex systems integrating numerous technologies, renders invaluable a structured educational program, that covers a range of material from traditional physics, pneumatics and electronics to mechatronics.

Einstein stated "It is the supreme art of the teacher to awaken joy in creative expression and knowledge". It is now even more essential to institute an ongoing training program which includes theoretical principles to complement knowledge acquired within the workplace.

The Camozzi Competence Centre is a department dedicated entirely to educating employees, suppliers and clients, offering continuously updated courses by qualified training personnel, including books and tools for continuous and effective learning.



THE UTILIZATION OF PNEUMATIC AUTOMATION IN THE INDUSTRIAL SECTOR

Knowledge, imagination, creativity
Progress begins here

Knowledge is our greatest asset, and when knowledge, imagination and creativity coalesce, ideas are born, which stimulate progress and growth.

The rapidity of technological evolution which characterizes this industry, demands that component manufacturers understand the principles upon which the operation of the products and respective applications are based.

In particular, process automation displays unique features within each sector with pneumatics representing one of the most common technologies, offering adaptable and high-performance solutions.

CAMOZZI TECHNOLOGY AND TAILOR-MADE INDUSTRIAL SOLUTIONS

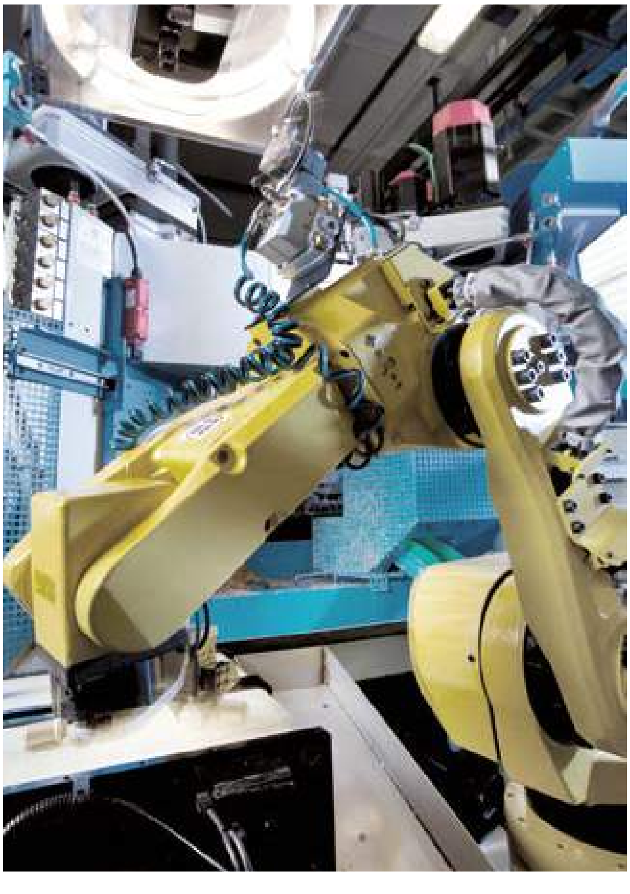
Camozzi Automation is one of the leading international groups operating in the field of pneumatic components for industrial automation.

With 6 manufacturing plants, structured according to the principles of "Lean Production", and supported by MARC (Mechatronic Application Research Center), which is dedicated to technological research, the Camozzi Group are designing and producing increasingly advanced components and systems integrating pneumatics, mechanics and electronics.

The global presence translates into the ability to support customers worldwide assuring assistance wherever products are installed.
Camozzi is positioned to accommodate companies who not only seek reliable components, but a true international partnership.

Camozzi Automation is an international network based in Italy with a presence on all continents, comprising sales offices and workshops in 21 countries, with exclusive distributors covering over 75 countries.

Continuous technological research, development and innovation within a structured and efficient framework whilst implementing top quality products and production processes define the Camozzi strategy. Emphasis is placed on the development of specific skills within each sector as a means to offering specific and effective solutions.



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CHAPTER 1
PHYSICS

The air

Every entity having mass and space dimensions is defined matter and is made up of minute particles called **"molecules"**. Matter exists in the following forms:

- **solid**, the molecules are rigidly bound, consequently the solids take on their own shape and volume;
- **liquid**, the molecules are not rigidly bound together, they possess volume and assume the shape of the container which holds them;
- **gaseous**, the molecules move freely - to the point that the distance between them varies continuously, as does their relative positions. Gases therefore have neither shape nor definitive volume.

In this section we focus on a characteristic of gas: **compression**, as a demonstration we use the example of the bicycle pump.

Figure 1

Pos. 1: through the hole placed at the end of the pump, the outside air is **drawn into** the cylinder (chamber) as a result of the piston and, its volume and its shape coincide with the size of the container, i.e. the chamber.

Pos. 2: by closing the hole in the pump and by exerting pressure on the piston, the air, which is unable to escape, will be forced to occupy a diminished space. As the volume that the air occupies is reduced, the air is thereby **"compressed"**.

Pos. 3: by further increasing the pressure on the piston, the volume occupied by air decreases further, although the number of air molecules remains constant. As the molecules are subjected to compression they are forced to occupy ever-decreasing spaces.

Assume that the total number of molecules contained in the pump is 900 and that the pump chamber has a volume of 150 cm^3; calculate the number of molecules present for each cm^3:

$$n° \text{ of molecules} / cm^3 = \frac{\text{tot. } n° \text{ of molecules}}{\text{volume}} = \frac{900}{150} = \mathbf{6}$$

Reducing the volumetric space, the air is compressed and the number of molecules per cm^3 increases.

Lowering the volume from 150 to 100 cm^3 and subsequently to 60 cm^3, calculate the number of molecules present:

$$n° \text{ of molecules} / cm^3 = \frac{\text{tot. } n° \text{ of molecules}}{\text{volume}} = \frac{900}{100} = \mathbf{9}$$

$$n° \text{ of molecules} / cm^3 = \frac{\text{tot. } n° \text{ of molecules}}{\text{volume}} = \frac{900}{60} = \mathbf{15}$$

In conclusion: as the air is compressed and the number of molecules remains unchanged, the number of **molecules per cm^3 increases.**

Figure 1

Pos. 4: compression has the property of influencing the temperature of the gas; the gas molecules mutually collide with each other and with the walls of the container, by decreasing the volume, the speed and number of collisions increases causing **the increase of temperature**.

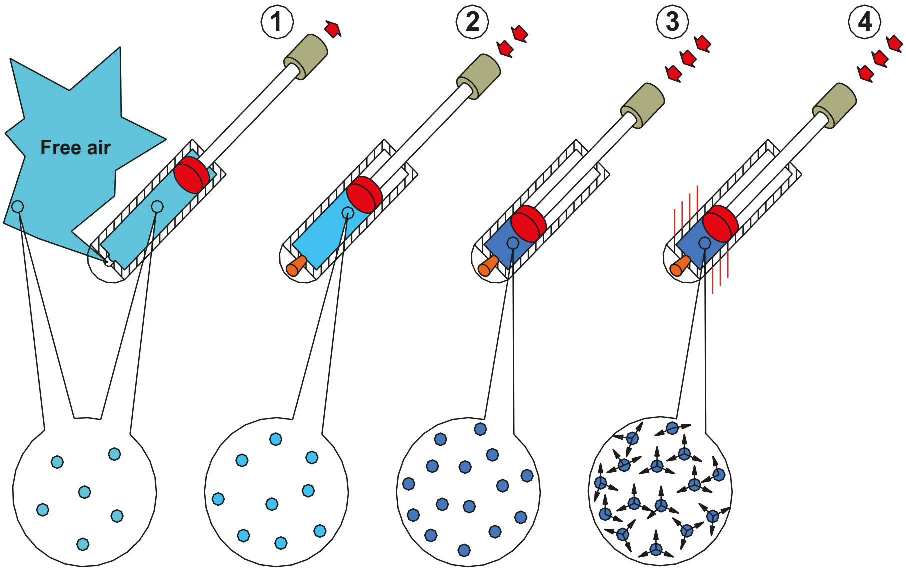


Fig. 1

Atmospheric pressure

Air possesses weight as a result of the Earth's gravity. The sensation of weight exerted on anything it comes into contact with is called **atmospheric pressure**.

The weight of the air is determined by the weight of 1 m^3 of dry air at a temperature of 20 *°C* and at a pressure of 760 *mm Hg* (760 *mm* of mercury column), and is equivalent to 1,03 *Kg*.

One of the characteristics of atmospheric pressure is that it varies according to the altitude. The maximum value is at sea level (zero altitude) and decreases as the altitude increases. This is due to the weight of the air on the lower layers of the atmosphere being greater than the weight on the upper layers. At sea level the atmospheric pressure is an average of 760 *mm Hg* and decreases by about 1 *cm* column of mercury per 100 *m* of elevation.
At an altitude of 1000 *m* the column has an average height of 66 *cm*. For high-altitudes, pressure decreases less rapidly.

The value of the atmospheric pressure can be measured by reproducing the experiment devised by the Italian physicist Evangelista Torricelli (1608-1647), a pupil of Galileo Galilei (1564-1642).

Figure 2
Pos. 1: take a glass tube closed at one end with length 1 *m* and with an internal diameter of about 12 *mm* (about 1 cm^2), and fill it completely with mercury. Hold a finger over the open end of the tube and invert it. Place the inverted tube in a basin also containing mercury, taking care not to release the end of the tube until it is immersed. When the finger is removed, mercury will flow from the tube into the bowl, the level of mercury retained in the tube can be measured from the surface of the mercury in the bowl to a height of 76 *cm*.

The mercury in the tube has not flowed entirely into the basin because of the atmospheric pressure acting on the free surface of the mercury in the basin. We can say that the atmospheric pressure is equal to the pressure exerted by a column of mercury 76 *cm* high.
With this information we can calculate the weight of the air.
Calculate the volume of the column:

$$V_{column} = \text{Area of the base} \ast \text{height} \qquad 1 \ast 76 = 76\ cm^3 \qquad V_{column} = \mathbf{76\ cm^3}$$

With the knowledge that the specific weight P_s of mercury is 0,01359 Kg/cm^3, we calculate the mass of the mercury column:

$$m_{column} = V_{column} \ast P_s \qquad 76 \ast 0{,}01359 = 1{,}03\ Kg \qquad m_{column} = \mathbf{1{,}03\ Kg}$$

Figure 2
Pos. 2: in order to balance the mercury column we must create an opposing Force, using weight for example.
The weight Force F_p corresponds to:

$$F_p = 9{,}81\ [N/Kg] \ast 1{,}03\ [Kg] = 10{,}1\ N \qquad F_p = \mathbf{10{,}1\ N}$$

Figure 2
Pos. 3: starting from the result of the previous experiment we calculate the height reached in a column of water instead of mercury:

$$V_{column} = \text{Area of base} \ast \text{height} \qquad 1\ [cm^2] \ast x\ [cm] = x\ [cm^3]$$

$$m_{column} = V_{column} \ast P_s \qquad x\ [cm^3] \ast m_{vol.}\ [Kg/cm^3] = 1{,}03\ Kg \qquad m_{column} = \mathbf{1{,}03\ Kg}$$

Knowing that the density $m_{vol.}$ of water is 0,001 Kg/cm^3 and that the mass of the mercury column is 1,03 *Kg* calculate the height of the water column *x*:

$$1{,}03\ [kg] = 1\ [cm^2] \ast x\ [cm] \ast m_{vol.}\ [Kg\ cm^3]$$

$$1{,}03\ [kg] = 1\ [cm^2] \ast x\ [cm] \ast 0{,}001\ [Kg/cm^3]$$

$$x = \frac{1{,}03\ [kg]}{1\ [cm^2] \ast 0{,}001\ [Kg/cm^3]} \qquad x = \frac{1{,}03\ [kg]}{0{,}001\ [Kg/cm]} \qquad \mathbf{x = 1030\ cm}$$

The height which the column of water must achieve to equal the atmospheric pressure is 10,3 *m*.

In the International System the unit of measurement of pressure is the **Pascal** *(Pa)* and is equal to the pressure of a Force of 1 *N* over 1 m^2.

$$1\,Pa = 1\,N/m^2$$

A much used multiple of *Pa* is the bar (even though it doesn't belong to the International System):

$$1\ bar \approx 100.000\ Pa \approx 0{,}1\ MPa$$

The table below illustrates the most common units of measure:

bar	Pascal	Kg/cm^2	cm H_2O	mm H_2O	mm Hg	P.S.I.
1	101.757	1,03	1033	10.330	760	14,69

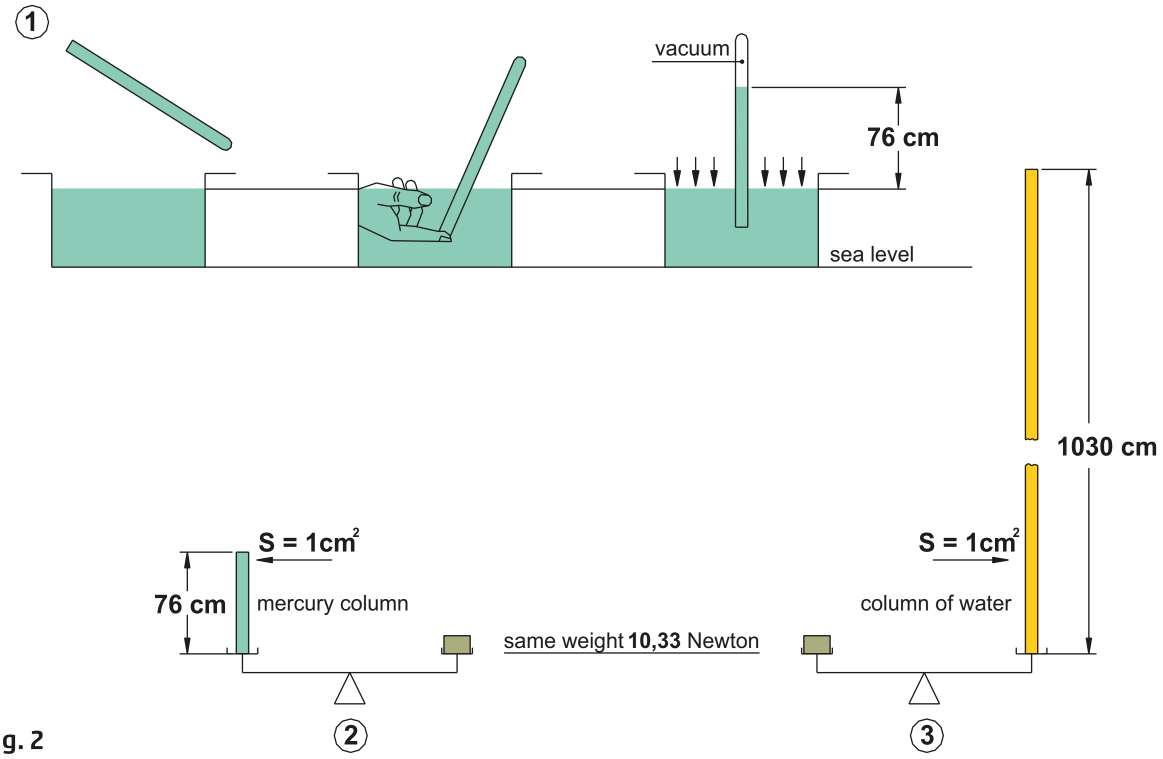


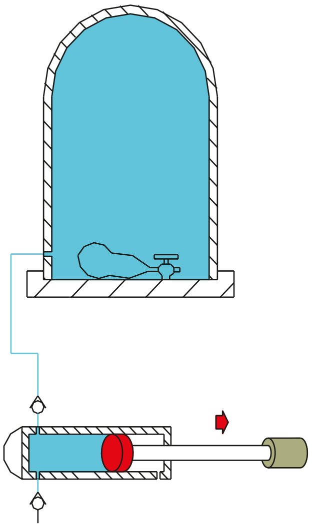
Fig. 2

Absolute and relative pressure

In this chapter we observe the phenomena whereby all gaseous bodies have a tendency to **expand**; we also observe the influence the atmospheric pressure has on a container full of water.

Figure 3
An empty balloon closed by a tap is positioned inside a glass container. At atmospheric pressure, the balloon is floppy, although it contains a certain amount of air. Removing the air from the container we observe that the balloon gradually inflates inside it, because as the air in the container was being gradually extracted, it exerted less and less Force on the balloon and resistance to the expansion of the air in the balloon was reduced. The air inside the balloon had a pressure value greater than that inside the bell.

This property is evident with balloons that float upwards: whereby increasing the altitude, the external pressure decreases and the gas inside the balloon expands until the balloon bursts.



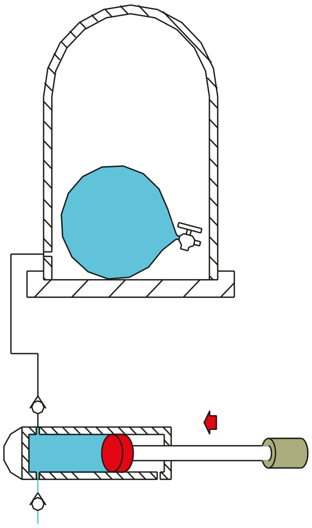


Fig. 3

Figure 4
The tap is closed, the tank is under pressure, for example with p = 5 *bar*. When the tap is opened, the air inside the tank releases into the atmosphere until the two pressures reach equilibrium. To achieve this equilibrium the molecules were transferred from inside to outside the tank.

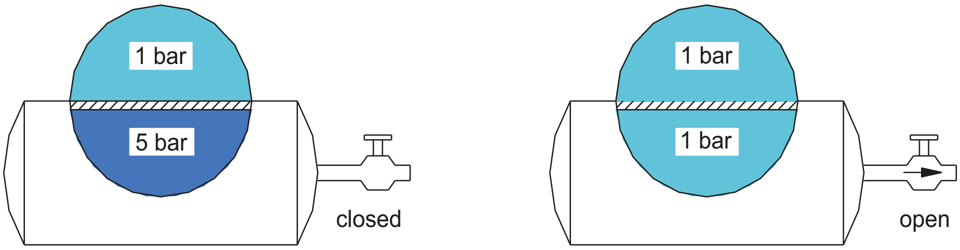


Fig. 4

Figure 5
Two tanks, with pressure p_1 = 5 *bar* and p_2 = 1 *bar*, are connected with a tap.
As in Fig. 4, the opening of the faucet creates a movement of air from tank 1 to tank 2, i.e. from the higher pressure to the lower, until the value of these two stabilizes at the equilibrium value p_e which we calculate from the average of the two pressures:

$$p_e = \frac{p_1 + p_2}{2} \qquad \frac{5\ [bar] + 1\ [bar]}{2} = 3 \qquad p_e = \mathbf{3\ bar}$$

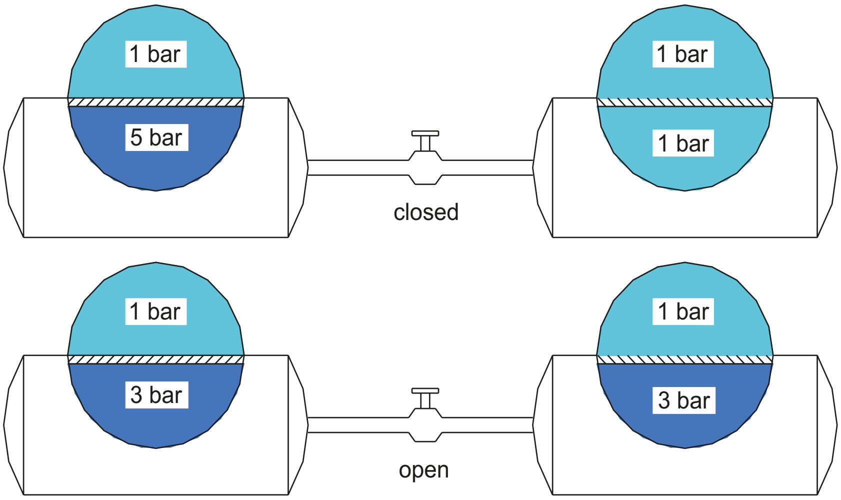


Fig. 5

Figure 6
There are two types of pressure: **absolute** and **relative**.
The absolute pressure is that which includes, in addition to the pressure that we generate through a pump, the atmospheric pressure.
The pressure of the air available to be used outside the receptacle is defined as **relative pressure** (or gauge pressure) - i.e. that indicated by the pressure gauge.

To measure atmospheric pressure we use the **barometer**, while to measure the pressure of a gas enclosed in a container we use the **manometer (pressure gauge)**. It is made of a metallic tube, with an elliptical section, in the shape of a circumference.

By varying the relative pressure at the end **B**, the tube varies its length. Point **A**, which is sensitive to this change, reflects this on the scale as a result of the rotary motion of a hinge. In this case, the gauge doesn't give us any value since the pressure difference between the inside and the outside of the tube is **zero**.

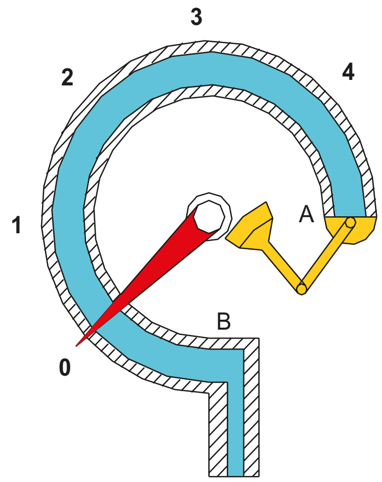


Fig. 6

Figure 7
Through this figure we can observe that, by increasing the pressure at the end **B**, the **A** end tends to straighten and move the index, as the resistance created by the external atmospheric pressure is overcome.
The difference between the two pressures determines the angular displacement of the index.

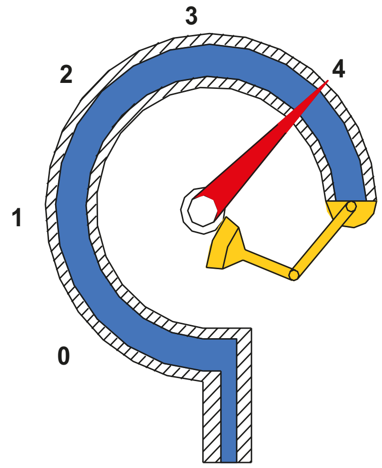


Fig. 7

Boyle's law

The state of a gas is described through three parameters: **Volume**, **Pressure**, and **Temperature**.
To understand the relationship between them, we study how a gas behaves by controlling one of these parameters and observing the behaviour of the others. A particular characteristic of gas is its capacity to expand and occupy the largest volume available. With the following examples, we study the change of pressure and volume at a constant temperature.

Figure 8
Pos. 1: a rigid transparent tube with a constant section and with a **U** shape is arranged in a vertical position with the long arm exposed and the short arm connected to a tap. Filling the mercury tube, the height of the mercury in the two arms will be equal, since the atmospheric pressure is acting on both surfaces. We close the tap, the volume of air present in the shorter arm, (subject to the atmospheric pressure) is denoted by V_X, with x as its height.
Pos. 2: we pour additional mercury through the open arm whereby the volume of the air in the short arm halves. We observe a difference in the level of mercury in the two arms of 76 *cm*, i.e. 1 *bar*.
Pos. 3: continuing to add mercury, we observe that when the volume of the trapped air becomes a third of the initial value, the difference in levels is 76 *cm* + 76 *cm* = 152 *cm*, i.e. 2 *bar*.

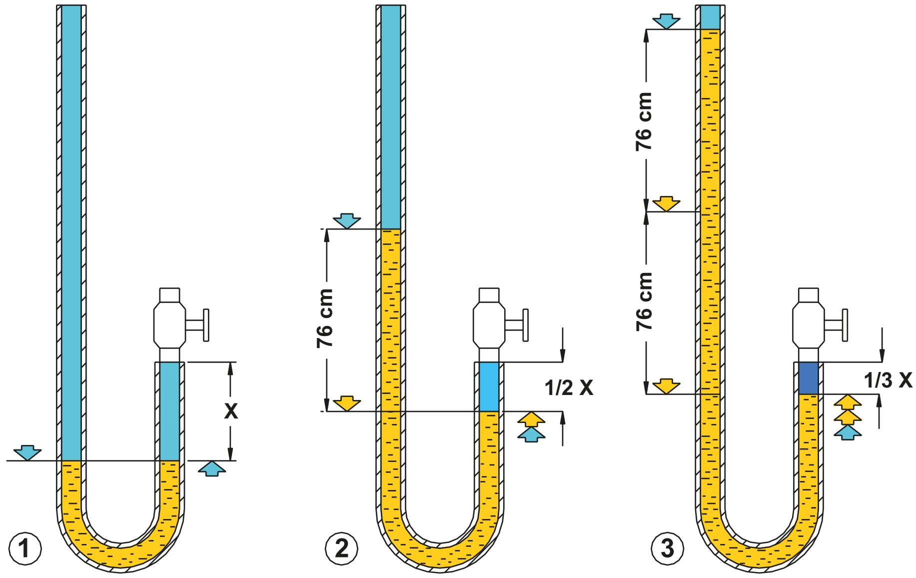


Fig. 8

Literal values are assigned to variables:

Initial Pressure	(Pos.1) = p_i	Final Pressure	(Pos. 2) = p_f
Initial Volume	(Pos.1) = V_i	Final Volume	(Pos.2) = V_f

From experimental results it can be determined that:

$$p_i : p_f = V_f : V_i \qquad p_i * V_i = p_f * V_f$$

This property was outlined by Irish chemist Robert Boyle (1627-1691) and is set forth in the law that bears his name: **at a constant temperature, the volume occupied by a gaseous mass is inversely proportional to the pressure to which the gas has been submitted**.

That is, if the pressure doubles, the volume of the gaseous mass will be reduced to half, in the same way, if the pressure is reduced to a third, the volume triples.
If *p* indicates the gas pressure and *V* its volume, Boyle's law can also be expressed with the formula:

$$p * V = constant$$

Example 1: a tank with volume $V_i = 2\ m^3$ is subjected to the pressure $p_i = 5\ bar$. What will its volume be at atmospheric pressure, keeping the temperature constant?

$$p_i * V_i = p_f * V_f \qquad V_f = \frac{V_i * p_i}{p_f}$$

$$\frac{2\ [cm^3] * 5\ [bar]}{1\ [bar]} = 10\ cm^3 \qquad V_f = \mathbf{10\ cm^3}$$

Example 2: an air mass undergoes a pressure $p_i = 2{,}5\ bar$ and occupies a volume $V_i = 0{,}5\ m^3$ at a constant temperature, an increase in pressure reduces the volume $V_f = 0{,}1\ m^3$.
What is the new pressure p_f?

$$p_i * V_i = p_f * V_f \qquad p_f = \frac{V_i * p_i}{V_f}$$

$$\frac{2{,}5\ [bar] * 5\ [m^3]}{0{,}1\ [m^3]} = 12{,}5\ bar \qquad p_f = \mathbf{12{,}5\ bar}$$

The effect of temperature on gases

All bodies, regardless of their state (solid, liquid, gas), undergo changes in volume when subjected to a temperature change. This phenomenon possesses different characteristics in the case of gases, which will take on the shape of the container that contains them. Containers of different dimensions can be "full" with an equal volume of gas, that is, the same amount of molecules. At constant temperature there is a fixed relationship between the volume of the container and the amount of gas molecules contained in it, i.e. between volume and pressure.
Therefore a variation in temperature will produce an effect on both the volume and the pressure, as we can see from the figures below.

Figure 9
Heading at constant pressure, the gas increases its volume

A closed container full of air is connected by a pipe to a basin containing water. At an ambient temperature, the air pressure inside the container is equal to the atmospheric pressure acting on the surface of the water in the container. (Air will not escape from the tube and water cannot enter it).
By heating the air in the container we can observe the bubbling water, when turning off the flame; we can observe the lowering of the water from its initial level and its ascent into the tube. The water bubbles, as the air heats up, need to occupy a larger volume and the bubbling water indicates the air molecules are exiting the tank. Once there is no heat source, the gas reduces in volume and the water, pushed by external pressure, enters the tube, occupying the volume that was previously occupied by the air molecules dispersed into the atmosphere during the heating phase.

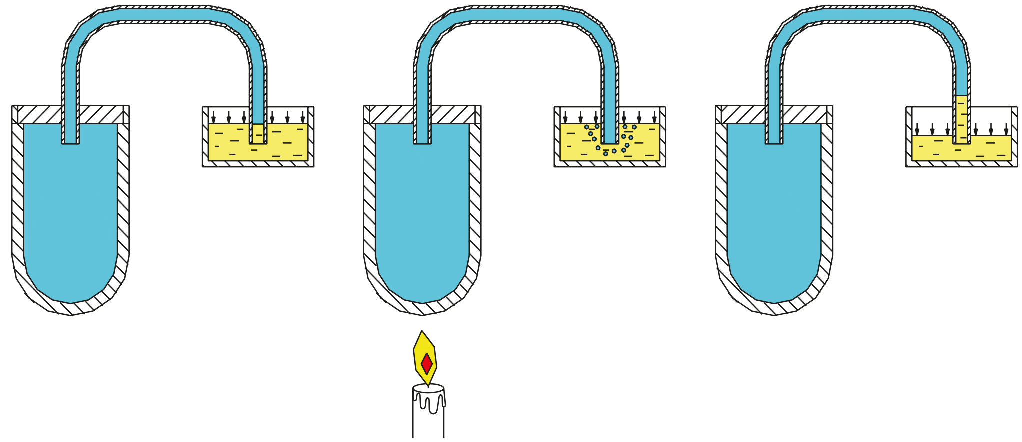


Fig. 9

Figure 10
Heating at constant volume: the gas increases its pressure

The same container, filled with air at an absolute pressure $p = 2$ *bar*, is connected to a pressure gauge, which indicates a relative pressure of 1 *bar*. This corresponds to the difference between the absolute pressure of 2 *bar*, inside the vessel and the atmospheric pressure of 1 *bar*. By warming the air in the container, the air expands but cannot escape, therefore its volume remains unchanged so it increases in pressure, as indicated by the manometer. As the air cools, the pressure returns to its original value, as indicated by the pressure gauge.

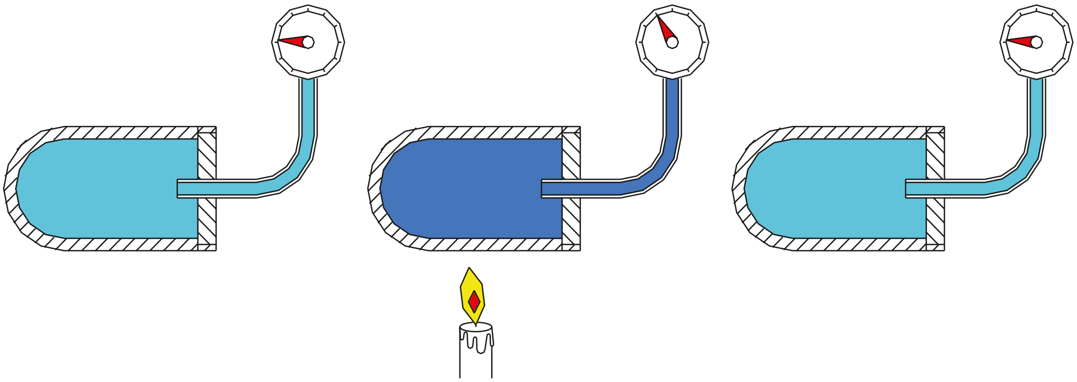


Fig. 10

When a gas is heated and has the ability to expand its volume, the pressure does not change, conversely when a gas is heated but does not have the ability to expand, it undergoes an increase in pressure.

Gay-Lussac's law

Gay-Lussac studied the transformation of gases as explained in the previous section.

The first Gay-Lussac's law states that:
at constant pressure the volume of a gas increases linearly with temperature.

When a gas is subject to a drop in temperature it transforms from gas to liquid.
This value corresponds to a temperature of absolute zero, the gas will re-expand if the temperature is increased.
Absolute zero is related to the Kelvin scale and corresponds to –273 degrees Celsius.

$$0\ K = -\ 273\ °C$$

Above this temperature the volume of a gas re-expands in a linear fashion.
A **coefficient for expansion of gas** defined as **α**, valid for all gases:

$$\alpha = 3.663 * 10^{-3}\ °C^{-1} \qquad \text{approx. equal to } 1/273\ °C^{-1}$$

If we imagine the gas in a closed container, the volume increase of **α**, represents the relative increase in pressure when its temperature increases by 1 °C.

The formula indicating this linearity when $p = K$ (constant) is:

$$V_t = V_0 * (1 + \alpha t)$$

V_t is the volume occupied by the gas at temperature t °C
V_0 is the volume occupied by the gas at temperature 0 °C
t is the temperature expressed in °C

Example 1: the temperature of a gas of volume 2 dm^3 increases from 273 K (t_i) to 373 K (t_f), Δt is 100 K (which also corresponds to 100 °C) therefore its volume becomes:

$$V_t = V_0 * \left(1 + \left(\frac{1}{t_1} * \Delta t\right)\right)$$

$$V_t = V_0 * \left(1 + \left(\frac{1}{273} * 100\right)\right) \qquad V_t = 2 * \left(1 + (0{,}0036 * 100)\right)$$

$$V_t = 2 * 1{,}36 \qquad V_t = \mathbf{2{,}72\ dm^3}$$

the gas volume increases about 36%.

Example 2: its previous volume experiences a drop in temperature of 100 K. From 373 K its volume becomes:

$$V_t = V_0 * \left(1 - \left(\frac{1}{373} * 100\right)\right)$$

$$V_t = 2{,}72 * \left(1 - (0{,}0026 * 100)\right) \qquad V_t = 2{,}72 * 0{,}74 \qquad V_t = \mathbf{2\ dm^3}$$

Example 3: from the final condition of the first case, reducing the temperature with 20 K (equivalent to 20°C) the volume becomes:

$$V_t = V_0 * \left(1 - \left(\frac{1}{353} * 20\right)\right)$$

$$V_t = 2{,}72 * \left(1 - (0{,}0028 * 20)\right) \qquad V_t = 2{,}72 * 0{,}94 \qquad V_t = \mathbf{2{,}56\ dm^3}$$

The second law of Gay-Lussac states that:
at constant volume the pressure of a gas increases linearly with temperature.

The formula for the calculation of pressure when $V = K$ (constant) is:

$$p_t = p_0 * (1 + \alpha t)$$

p_t is the pressure at t °C
p_0 is the pressure at 0 °C
t is the temperature in °C

Increasing the temperature of a gas from 0 °C to 100 °C, the pressure becomes:

$$p_t = p_0 * \left(1 + \left(\frac{1}{t_1} * \Delta t\right)\right)$$

$$p_t = p_0 * \left(1 + \left(\frac{1}{273} * 100\right)\right) \qquad p_t = p_0 * \left(1 + \left(0{,}0036 * 100\right)\right) \qquad p_t = \mathbf{p_0} * \mathbf{1{,}36\ dm^3}$$

the pressure of the gas increases by about 36%.

If the temperature is reduced to values lower than 0 °C, the pressure p_t is proportionally reduced to zero at a temperature of –273 °C. At this temperature, defined as absolute zero, all gases are now in the liquid state.
In fact most gases liquefy before reaching this temperature, nitrogen at –196 °C,hydrogen at –253 °C, helium at –269 °C.

In the case of a temperature reduction the previous formula changes slightly:

$$p_t = p_0 * \left(1 - \left(\frac{1}{t_1} * \Delta t\right)\right)$$

Example: the initial pressure is 10 *bar*, if it causes a decrease of temperature of 1 °C, the pressure becomes:

$$p_t = p_0 * \left(1 - \left(\frac{1}{273} * 1\right)\right) \qquad p_t = 10 * (1 - 0{,}0036) \qquad p_t = \mathbf{9{,}96\ bar}$$

for a reduction of 100 °C, the pressure is reduced to a value of:

$$p_t = p_0 * \left(1 - \left(\frac{1}{273} * 100\right)\right) \qquad p_t = 10 * (1 - 0{,}36) \qquad p_t = \mathbf{6{,}33\ bar}$$

for a reduction of 273 °C, the pressure is reduced to a value of:

$$p_t = p_0 * \left(1 - \left(\frac{1}{273} * 273\right)\right) \qquad p_t = 10 * (1 - 1) \qquad p_t = \mathbf{0\ bar}$$

at a temperature of –273 °C the pressure becomes 0.

The unit of measure commonly used for temperature is the degree Celsius (°C) and relates to a temperature scale that registers the freezing point of water as 0 °C and the boiling point as 100 °C under normal atmospheric pressure. The unit of measurement used in the International System is the degree kelvin, which has a value equal to that of 1 degree Celsius, even if the scale is different.

$$0\ ^\circ C = \mathbf{273\ K} \qquad 100\ ^\circ C = \mathbf{373\ K}$$

Figure 11
A tank with volume V_1 consists of two cylinders of different diameters, a piston of negligible weight separates the absolute pressure (inside the tank) and the atmospheric pressure. We assume that the pressure gauge is set at 0. The room temperature i.e. $T = 293\ K$ (20 °C).

a) Maintaining a constant temperature T. If the piston is pulled outwards the volume inside the container increases, the pressure gauge decreases falling below the value of zero, because the pressure inside of V_2 is less than atmospheric pressure.
b) If a Force is applied which pushes the piston inwards, the volume of the tank will decrease while the indicator of the pressure gauge will increase because the pressure inside of V_2 is greater than atmospheric pressure.

$$V_1 : V_2 = P_2 : P_1$$

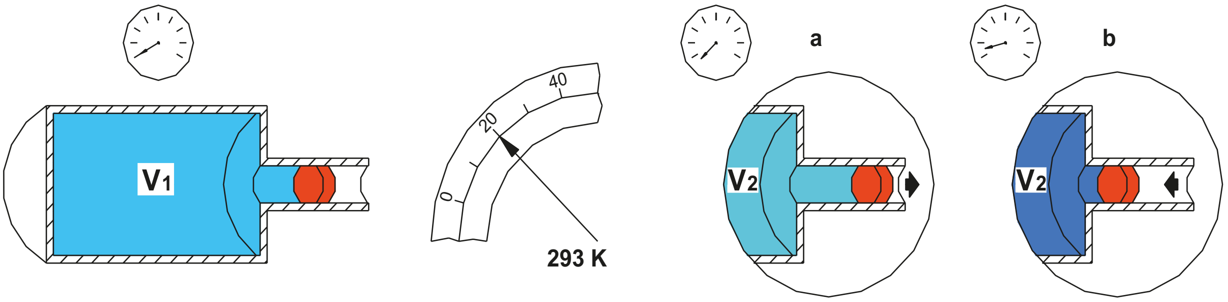


Fig. 11

Figure 12
Assume that we keep the temperature constant, and we act with an external Force on the piston, we raise the ambient temperature of 20 °C bringing it to a value $T = 313\ K$.
The momentum of the molecules, following their expansion, moves the piston outward until the volume increase has compensated for the higher pressure.

$$V_1 : V_2 = T_1 : T_2$$

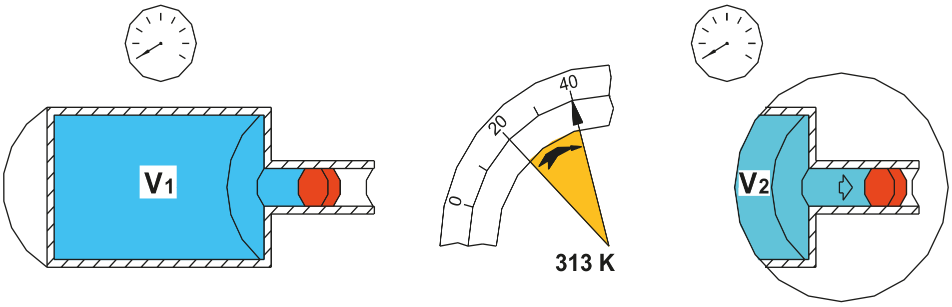


Fig. 12

Figure 13

If the temperature is lowered, the volume taken up by the air molecules inside the tank is reduced, a kind of vacuum is created, the piston is drawn inwards until pressure equilibrium has been achieved.

$$P_1 : P_2 = T_1 : T_2$$

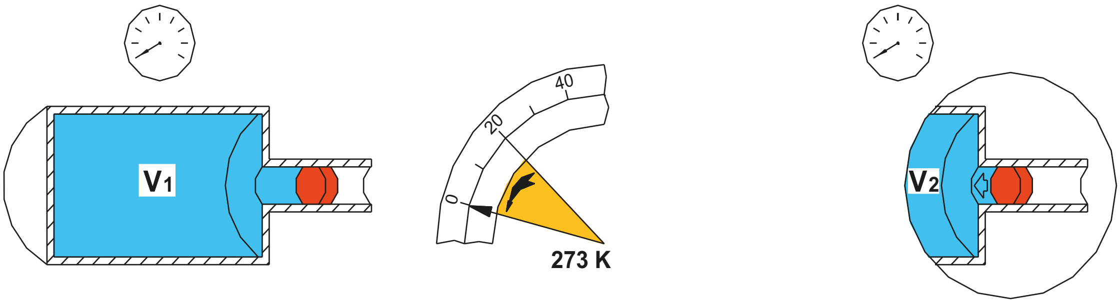


Fig. 13

Example 1: a gas occupies a volume of 0,5 m^3 at a temperature of 283 *K*, what will its volume be at 323 *K* if the pressure remains constant?

$V_1 = 0{,}5\ m^3$ $T_1 = 283\ K$ $T_2 = 323\ K$ $V_2 = ?$

$V_1 : V_2 = T_2 : T_1$ $0{,}5 : V_2 = 283 : 323$ $V_2 = (0{,}5 \ast 323) / 283 = \mathbf{0{,}57\ m^3}$

Example 2: a cylinder is full of gas at a pressure of 2 *bar* and at a temperature of 283 *K*, remaining exposed to the sun it warms to 50 °*C*. What will the pressure within the cylinder be?

$P_1 = 2\ bar$ $T_1 = 283\ K$ $P_2 = ?$ $T_2 = T_1 + 50 = 333\ K$

$P_1 : P_2 = T_1 : T_2$ $2 : P_2 = 283 : 333$ $P_2 = (2 \ast 333) / 283 = \mathbf{2{,}35\ bar}$

Relationship between pressure, volume and temperature

As we have previously demonstrated the relationship between Pressure, Volume and Temperature is interdependent: through changing one, you change the other. In summary:

$V_1 : V_2 = p_2 : p_1$	(Boyle's law) at a constant temperature *V* and *p* are inversely proportional
$V_1 : V_2 = t_1 : t_2$	(1st Gay-Lussac) at constant pressure *V* and *t* are directly proportional
$p_1 : p_2 = t_1 : t_2$	(2nd Gay-Lussac) at a constant temperature *p* and *t* are directly proportional

Using these formulae we solve the following problems:

a cylinder with an internal diameter $d = 50\ mm$ is filled with a gas which at a temperature of $t_1 = 20\ °C$ occupies a volume $V_1 = 0{,}98\ dm^3$; a load $F_1 = 980\ N$ is applied on the piston. Calculate the displacement of the piston with an increase of double the Force applied ($F_2 = 2 \ast F_1$) at an ambient temperature $t_2 = 50\ °C$.

Calculation of the volume reached by the gas.

Case A

Figure 14
1st phase: assuming that the pressure remains constant. Using Gay-Lussac's first law calculate the volume V_2 of the gas which is heated from a temperature $t_1 = 20 + 273 = 293\ K$ to a temperature $t_2 = 50 + 273 = 323\ K$.

$$V_1 : V_2 = t_1 : t_2 \qquad V_1 * t_2 = V_2 * t_1 \qquad V_2 = \frac{V_1 * t_2}{t_1}$$

$$V_2 = \frac{0{,}98\ [dm^3] * 323\ [K]}{293\ [K]} \qquad V_2 = \mathbf{1{,}08\ dm^3}$$

Due to only the increase of the temperature of the gas, the volume has increased $V_2 = \mathbf{1{,}08\ dm^3}$.

2nd phase: we observe the behaviour of the volume V_2 with an increase of double the Force applied on the piston.

$$F_2 = 2 * F_1 \qquad F_2 = 2 * 980\ N \qquad F_2 = \mathbf{1960\ N}$$

As a result of the increase in the Force F_2, applied to the piston, there is a reduction in the volume V_3.

$$V_2 : V_3 = F_2 : F_1 \qquad V_3 = \frac{V_2 * F_1}{F_2}$$

$$V_3 = \frac{1{,}08\ [dm^3] * 980\ [N]}{1960\ [N]} \qquad V_3 = \mathbf{0{,}54\ dm^3}$$

Under the action of the Force F_2 and temperature t_2 the volume is reduced until it reaches $V_3 = \mathbf{0{,}54\ dm^3}$.

Case B

The unit of measurement of the pressure is Kg/cm^2, it is possible to calculate the value of the pressure using the value of the load F_1, F_2 and the surface of the piston.

Figure 14
1st phase: calculation of the area of the piston

$$S = r * r * \pi \qquad S = 25 * 25 * 3{,}14 \qquad S = \mathbf{1962{,}5\ mm^2} \qquad S = \mathbf{19{,}6\ cm^2}$$

Calculate the initial pressure p_1:

$$p_1 = \frac{F_1}{S} \qquad \frac{980\ [N]}{19.6\ [cm^2]} \cong 50\ N/cm^2 \qquad p_1 \cong \mathbf{5\ Kg/cm^2}$$

Figure 14
2nd phase: calculation of the final pressure p_2:

$$p_2 = \frac{F_2}{S} \qquad \frac{1960\ [N]}{19.6\ [cm^2]} \cong 100\ N/cm^2 \qquad p_2 \cong \mathbf{10\ Kg/cm^2}$$

Load and pressure are directly proportional, using Boyle's law and substituting the known values gives:

$$V_2 : V_3 = p_2 : p_1 \qquad V_2 * p_1 = p_2 * V_3 \qquad V_3 = \frac{V_2 * p_1}{p_2}$$

$$V_3 = \frac{1{,}08\ [dm^3] * 50\ [N / cm^2]}{100\ [N / cm^2]} \qquad V_3 = \mathbf{0{,}54\ dm^3}$$

In both cases the result is $V_3 = \mathbf{0{,}54\ dm^3}$.

Another method that implements the two laws of Gay-Lussac

$$(p_1 * V_1) : t_1 = (p_2 * V_3) : t_2 \qquad \frac{p_1 * V_1}{t_1} = \frac{p_2 * V_3}{t_2}$$

$$V_3 = \frac{p_1 * V_1 * t_2}{p_2 * t_1}$$

$$V_3 = \frac{50\,[N/cm^2] * 0{,}98\,[dm^3] * 323\,[K]}{100\,[N/cm^2] * 293\,[K]} \qquad V_3 = \mathbf{0{,}54\ dm^3}$$

With the formula calculating the volume, it is possible to derive the change in height of the piston.

$$V_1 = S * h_1 \qquad h_1 = \frac{V_1}{S} = \frac{980\,[cm^3]}{19{,}6\,[cm^2]} \qquad h_1 = \mathbf{50\ cm}$$

$$V_3 = S * h_2 \qquad h_2 = \frac{V_3}{S} = \frac{540\,[cm^3]}{19{,}6\,[cm^2]} \qquad h_2 = \mathbf{27{,}5\ cm}$$

The piston is lowered by:

$$h_1 - h_2 = 50\,[cm] - 27{,}5\,[cm] = \mathbf{22{,}5\ cm}$$

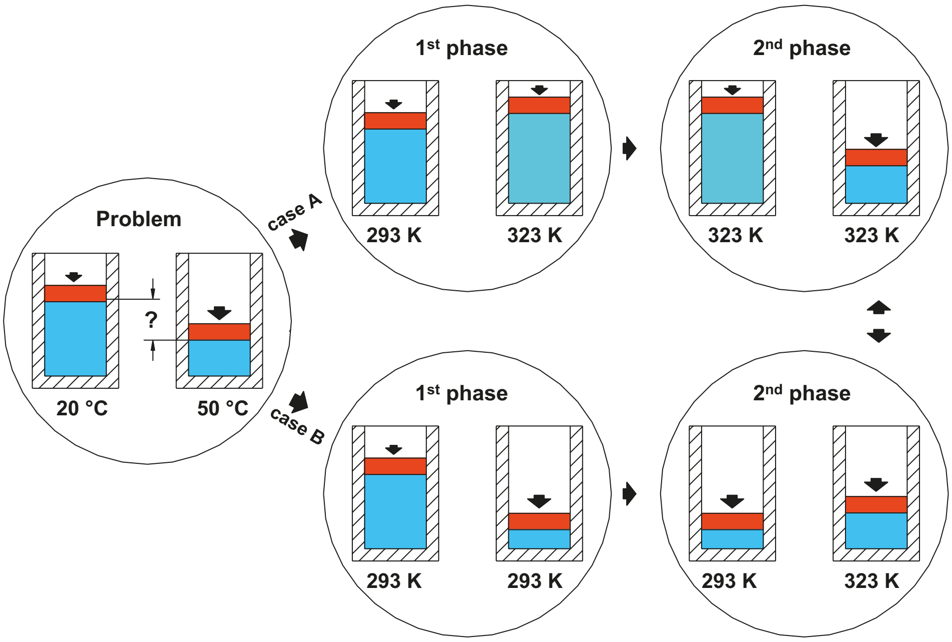


Fig. 14

Pressure and flow rate

Part 1

The two fundamental physical quantities of pneumatics are: **pressure** and **flow rate**.

The flow rate represents the volume of fluid that crosses the section of a duct in a certain unit of time. The flow rate Q is defined as the ratio between the volume ΔV of the fluid that passes through the duct and the time interval Δt employed to pass it through or as the product of flow section S and fluid velocity ν, if they are known.

$$Q = \frac{\Delta V}{\Delta t} \qquad Q = S * \nu$$

In the International System it is measured in m^3/s.

The flow rate of a valve is influenced by two factors:

- the flow section;
- the weight of the column of liquid which acts on the valve (remember that a water column of height 10,33 *m* exerts a pressure of 1 *bar*).

Example:

A tank has an outlet valve **A** and an inlet valve **B** with the same section ($S_A = S_B$) both with an adjustable flow. This can be mapped using a Cartesian axis diagram, in which the *x*- axis represents the time *t* necessary to empty the tank and the *y*- axis the water level *L*. Observe the following situations.

Figure 15

Pos. 1: both valves are closed. The diagram has a point at 0,0.

Pos. 2: drain valve **A** is closed and the inlet valve **B** open. The tank is filled up to the level L_p (full tank level). In the diagram, $t = 0$ and $L = L_p$.

Pos. 3: inlet valve **B** is closed and the exhaust **A** valve open. The water level is lowered until the tank is completely empty (the emptying time t_s depends on S_A). In the diagram we obtain a segment that goes from L_p to t_s (time required for emptying the tank).

Pos. 4: both valves are open. There's an equal amount of water entering and exiting, the water level in the tank remains constant and the diagram shows a line with $L = L_p$.

Tests have verified that from a hole with a section $S = 1\ cm^2$ ($1 * 10^{-4}\ m^2$) with a pressure $p = 1\ bar$, water leaks at about 84 l/min = 1,4 l/s.

In the following exercise calculate the level L_e so that the amount of water inside the tank is constant, knowing the flow rate of the valve **B** has been adjusted to provide 40 l/min, i.e. 0,66 l/s.

We proceed by assuming $Q_A = Q_B$ and therefore $\nu_A = \nu_B$, as the sections of the two valves are identical. Through Q_B it is possible to calculate the velocity of the water passing through valve **B** with the inverse formula.

$$\nu_B = \frac{Q_B}{S} = \frac{0{,}66\ [l/s]}{1 * 10^{-4}\ [m^2]} = \frac{0{,}66 * 10^{-3}\ [m^3/s]}{1 * 10^{-4}\ [m^2]} \qquad \nu_B = \mathbf{6{,}6\ m/s}$$

To obtain the height of equilibrium L_e, we apply Torricelli's law: the speed with which the water exits from a hole of a tank is equal to the speed in a vacuum which a stone would possess if it were dropped from a height equal to the distance from the surface of the water to the hole.

$$\nu_A = \sqrt{2g * L_e}$$

$$L_e = \frac{\nu_A^2}{2g} \qquad \frac{6{,}6^2\ [m/s]^2}{2 * 9{,}81\ [m/s^2]} \qquad L_e = \mathbf{2{,}22\ m}$$

To get an output flow equal to the input flow rate $Q_A = Q_B$, we set the speed ν_A equal to ν_B ($\nu_A = \nu_B$) and using Torricelli's law we find the height of the liquid required to verify these equalities; in the example just shown we have:

$$L_e = \mathbf{2{,}22\ m} \qquad Q_A = Q_B = \mathbf{0{,}66\ l/s}$$

With the same procedure, we calculate the height of equilibrium L_e assuming Q_B = **120 l/min** = **2 l/s**.

$$v_B = \frac{Q_B}{S} = \frac{2\,[l/s]}{1 * 10^{-4}\,[m^2]} = \frac{2 * 10^{-3}\,[m^3/s]}{1 * 10^{-4}\,[m^2]} \qquad v_B = \mathbf{20\ m/s}$$

$$v_A = \sqrt{2g * L_e} \qquad L_e = \frac{v_A^2}{2g} \qquad \frac{20^2\,[m/s]^2}{2 * 9{,}81\,[m/s^2]} \qquad L_e = \mathbf{20{,}38\ m}$$

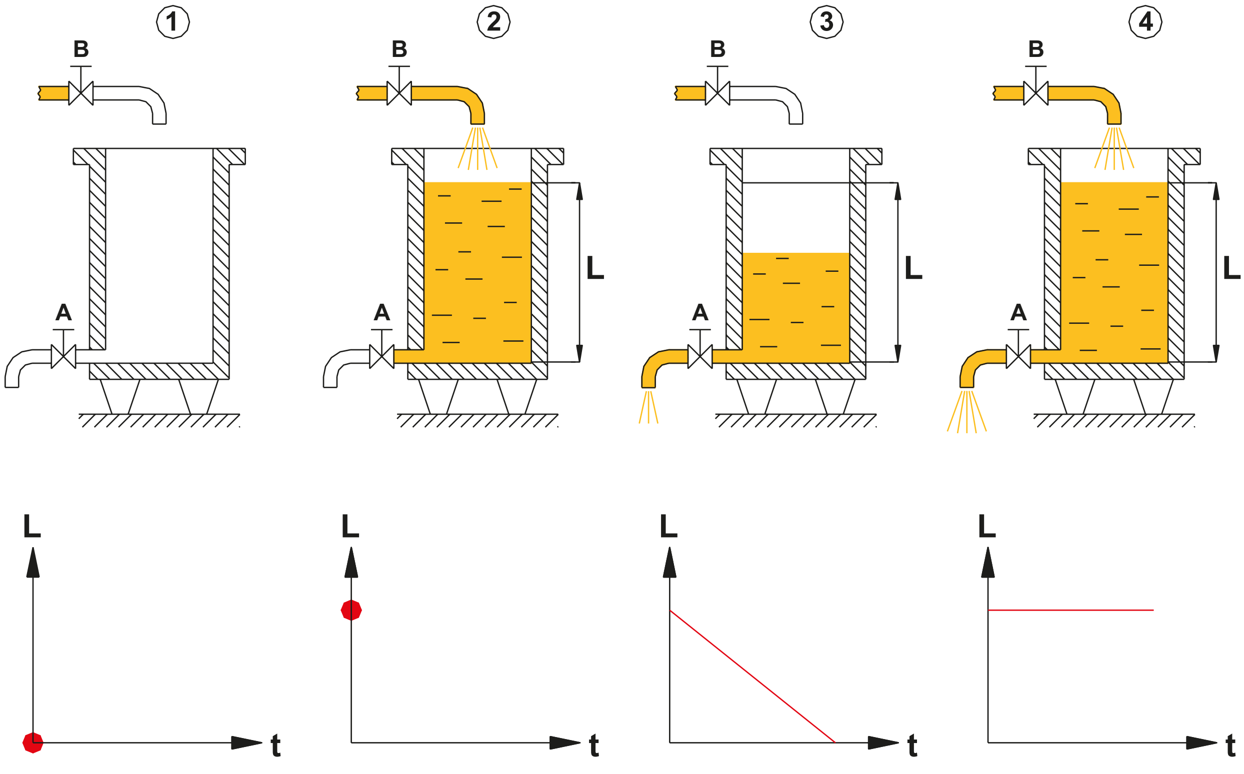


Fig. 15

Part 2
In the previous section, we observed that by maintaining a constant input and output flow rate, the height of the liquid in the tank is maintained at equilibrium.

Figure 16
Pos. 1: two pipes, with relative valve sections whereby $S_{A1} = S_{A2} = S$ are connected to the tank filled with water up to the level *L*. We open the valve **B** ($S_B > S$) and subsequently the valve **A2**.
Once the equilibrium height *L* is reached, i.e. when the quantity of incoming liquid will be equal to the quantity of out-flowing liquid, we position a basin for collecting the liquid at the outlet of the valve **A2**.
After a unit of time *t* we verify the height *h* of the collected liquid.
Pos. 2: we modify the previous system by also opening the valve **A1** and collecting the liquid in two containers. Now the time *t* to reach the level *h* in the two basins is greater than the time noted in Pos. 1 ($t\,2 > t\,1$).
We observe that the variation of outflow is not compensated by an appropriate change in the inlet flow, resulting in changes in the level **L1** and therefore of the pressure.
If the valve **B** had been adjusted in order to maintain a constant level **L1** = *L*, the same pressure of Pos. 1 would have been exerted on **A1** and **A2** and the filling time of the basin would have been $t2 = t1$.
Pos. 3: let us now consider a single outlet pipe **A** of section $S_A = 2S$
In the time *t1* a quantity of water equal to the sum of the flow of the valves **A1** and **A2** flows through the valve **A** and the underlying basin is filled up to a level 2*h*.

One can draw the following conclusions:

At equal **pressure**, the **flow rate** depends on the difficulty of the passage through the pipe or valve, i.e. the cross section. The larger the section the more easily the fluid will pass through.

With equal sections, a reduction of the pressure leads to a decrease in the flow, that is, to a smaller amount of fluid in motion per time unit.

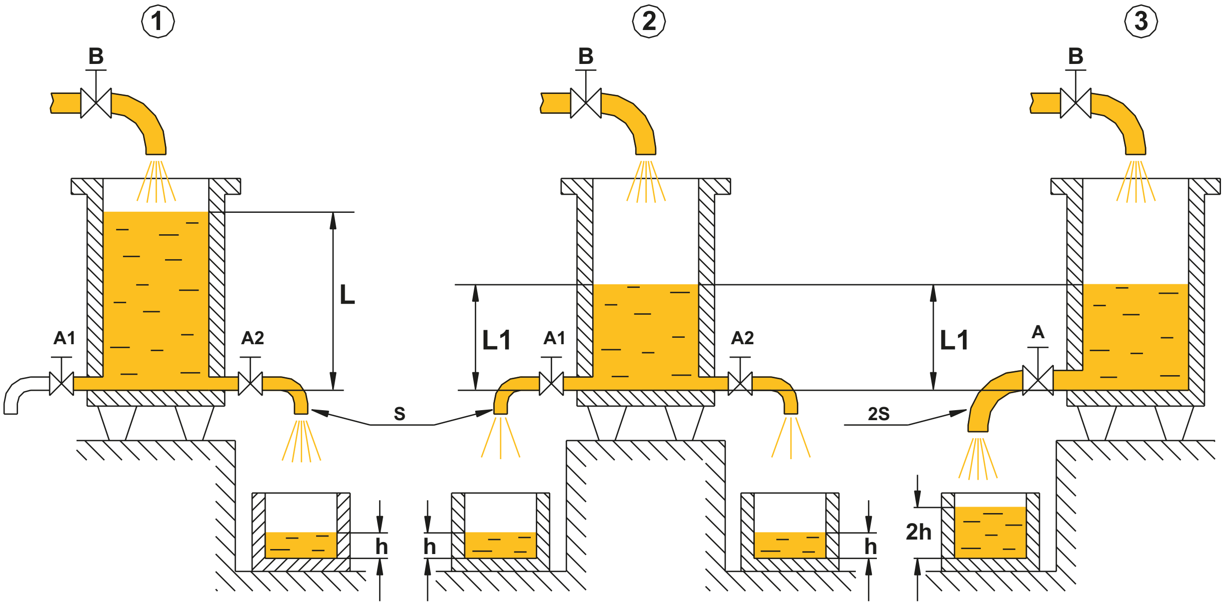


Fig. 16

Pascal’s principle

This section examines the French scientist Blaise Pascal’s principle.
The differences between a “principle” and a “law” are:

- a “law” can always be expressed by a formula which relates the variables of a given phenomenon;
- a “principle”, is a formal statement of a useful fact or relationship.

Observe the illustrations:

Figure 17
Two **U**-shaped tubes with the same section contain two fluids, one is gaseous and the other liquid. Pistons exerting the same Force *F*act on both surface areas of the tube’s arms. From the two illustrations we can detect that the levels reached by the pistons are different if compared to each other and equal if viewed separately. The level reached by the pistons containing gas is lower than that containing liquids, this is due to the fact that gases can be compressed.

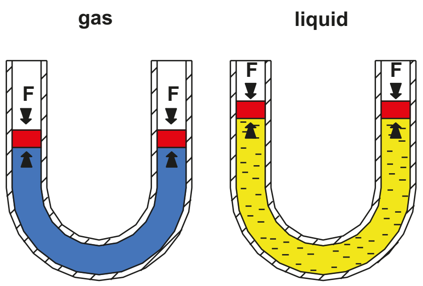


Fig. 17

Figure 18

Pos. 1: a tank containing liquid is connected to the pistons **A** and **B** of equal section which exert the same Force *F*. Regardless of the section of the tank and of the mounting position, the level of the pistons is identical.
By increasing the Force *F* on one of the two pistons, the other will rise.

Pos. 2: a third piston **C**, of equal section, is added next to **B**. Exerting a Force *F* only on piston **A**, pistons **B** and **C** will rise equally. Applying the same Force *F* on the pistons **A** and **B**, they will achieve equilibrium, piston **C** will move upwards. In the case in which the same Force *F* is applied to piston **C**, the three pistons will be positioned at the same height.

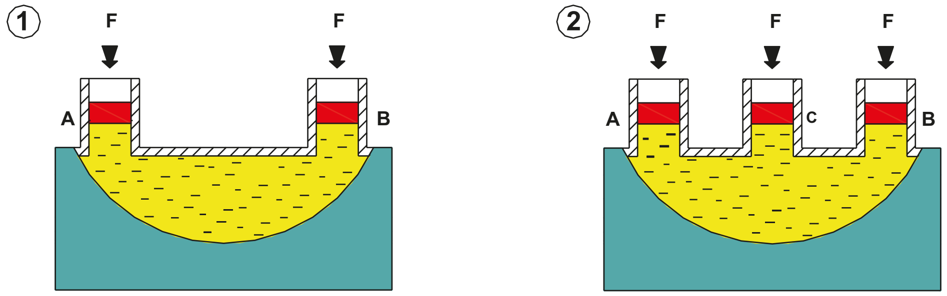


Fig. 18

Figure 19

Pos. 3: the pistons **B** and **C** (with the same section) are now replaced by a single piston **E** whose area is the sum of the areas **B** and **C** ($S_E = S_B + S_C$). By applying a Force *F* on only piston **A**, it will be lowered and consequently piston **E** rises. Maintaining the Force *F* on piston **A** and exerting the same Force *F* on piston **E**, the larger piston **E** will lower, however it will still have a higher level than **A**. Applying the Force *2F* to piston **E** will bring it into equilibrium with **A**.

Pos. 4: eliminate the piston **E** and plug the tank. Introducing a pressure gauge, we note that in every point of the metal sheet of the tank the pressure is the same.

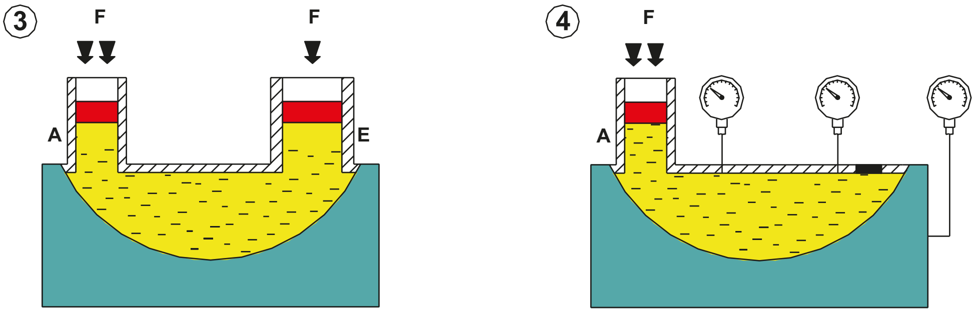


Fig. 19

The explanation of the phenomena described above is illustrated in **Pascal's principle**, which states that: **pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure ratio (initial difference) remains the same**.

Figure 20

Observe the physical effects of this principle:
Assuming that the piston **A** has a section $S_A = 5\ cm^2$ and the Force $F_A = 100\ N$;
calculate the pressure exerted on the fluid
($1\ N/m^2 = 1\ bar = 1 * 10^{-5}\ P_a$)

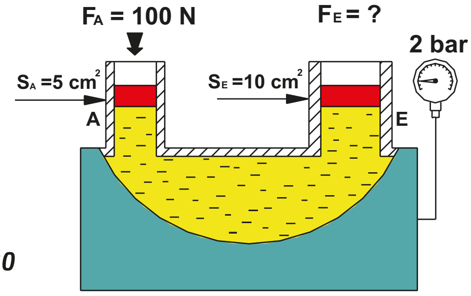


Fig. 20

$$p_A = \frac{F_A}{S_A} \qquad \frac{100\ [N]}{5\ [cm^2]} \qquad \frac{100\ [N]}{5 * 10^{-4}\ [m^2]} \qquad p_A = 2 * 10^{-5}\ N/m^2 \qquad p_A = \mathbf{2\ bar}$$

We now calculate the Force F_E to be applied on the surface **E** in order to keep it in equilibrium with the piston **A**.

$$p_E = \frac{F_E}{S_E} \qquad F_E = p_E * S_E \qquad 2 * 10^5\ [N/m^2] * 10^{-3}\ [m^2] = 200\ N \qquad F_E = \mathbf{200\ N}$$

Venturi’s principle

In everyday language, the word “**phenomenon**” is used to describe an extraordinary fact, in Physics, the term phenomenon is used as a **description of every variation of position and state of a body**.

If a thin disc of section **S** is suspended between the fingers and moved through the air at a constant speed in a direction perpendicular to the surface of the disc: the movement causes a perceivable reaction, due to the resistance from the air; this reaction has a constant value presuming the speed of the disc does not vary, and continues as long as the movement lasts. Repeat the test with another disk, the surface of which is smaller than the previous disc, for example **S/2**: maintaining approximately the same speed of movement, we note a lower air resistance.

Figure 21
Pos. 1: we illustrate the previous experiment showing an image of the flow of air demonstrating that with equal atmospheric pressure the resistance of the air is in proportion to the section of the body in motion.
Pos. 2: in this case the pressured air flows inside a body, a pipe with an internal section, i.e. the opposite situation of Pos. 1. We denote the two sections **AA** and **BB**.

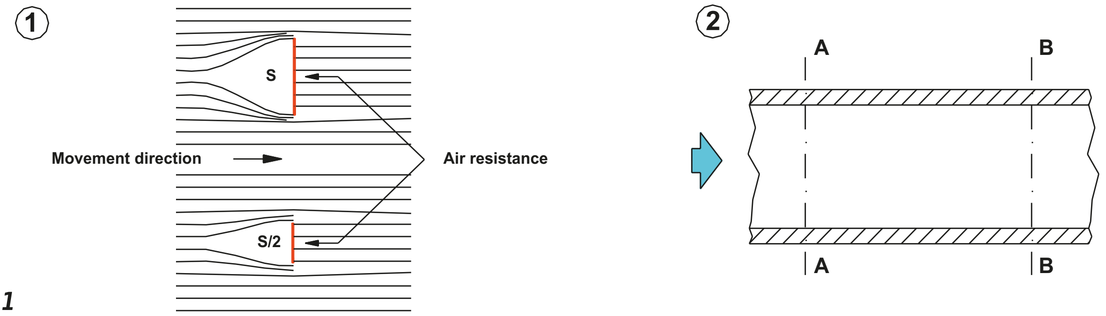


Fig. 21

Figure 22
Pos. 3 and **4**: at constant pressure the volume of air molecules in transit in sections **AA** and **BB** is equal and constant regardless of the distance between the two sections: the fluid flows at a uniform speed as there are no obstacles that oppose its movement.

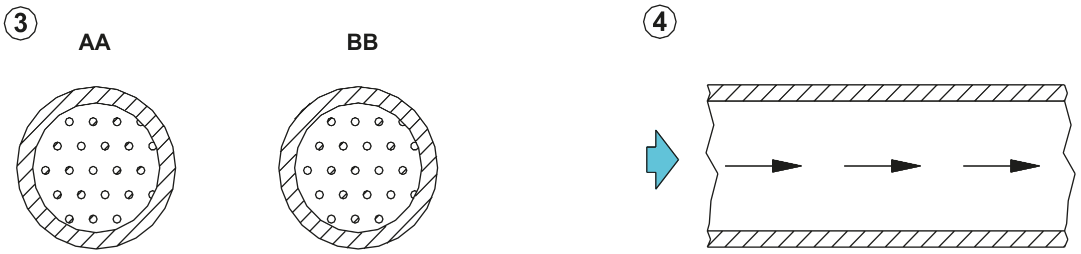


Fig. 22

Figure 23
Pos. 5 and **6**: Consider a tube with a smaller central section and joined to the funnel, the incoming air is at the same pressure as in the previous example, however corresponding to the reduced section **DD**, the air encounters resistance to its passage. Being of constant input pressure, the air will be forced to increase speed.

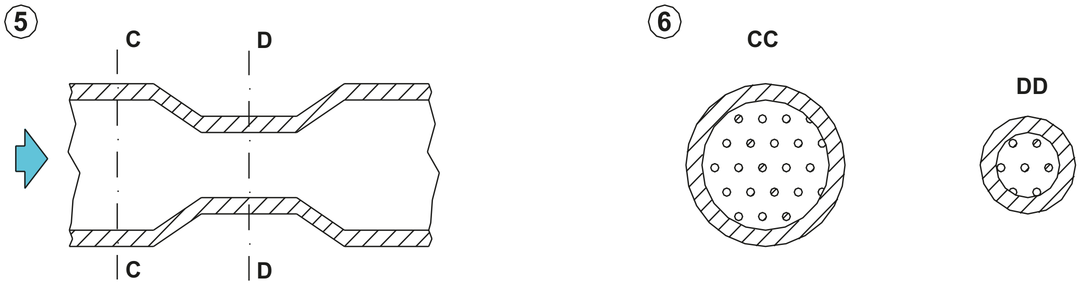


Fig. 23

Figure 24
Pos. 7: the physical law that governs this phenomenon states that: **in a given time period and at equal pressure, the same quantity of air will always pass through two pipes of different section**.
Observing the sections **CC** and **DD** in Fig. 23 - Pos. 6 we can deduce that, in order to maintain the same flow rate, the air molecules re: section **DD** increase their speed relative to those of section **CC**.
Pos. 8: the **Venturi effect** states: **in the area of a tube where the fluid velocity increases, its pressure decreases**.
Pos. 9: this phenomenon, which takes its name from the Emilian physicist Giovanni Battista Venturi (1746-1822), finds applications in various daily applications due to a simple device called a Venturi tube.
It is a shaped tube whereby, along the bottleneck, there is an opening connected to a tube with some liquid. When the air in the tube starts to circulate, the liquid is drawn to the bottleneck since there is a lower pressure. Where it meets with the flow of the air it atomizes and becomes suspended in the next section.

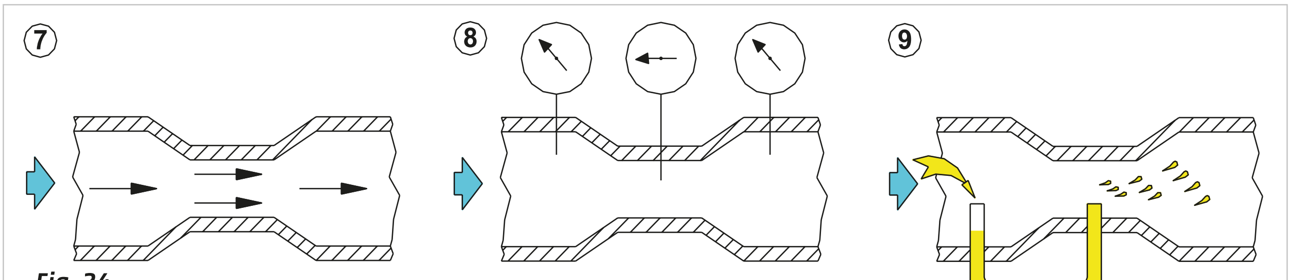


Fig. 24

Mechanical concepts

The study of mechanics is considered to be divided into three fundamental branches:
"**Statics**" this deals with the equilibrium of bodies subject to a system of Forces applied to them;
"**Kinematics**" describes the motion of bodies regardless of the causes of motion;
"**Dynamics**" i.e., the study of the movement of a body in relation to the causes generating this motion.
A body can assume different "states"
State of rest: maintaining the same position with respect to a fixed reference system over a passage of time.
State of motion: changing the position with respect to the fixed reference system, over the passage of time.

Figure 25
Pos. 1: a **Force**: is any influence, which causes an object to undergo a certain change, i.e., changing the state of rest or motion of a body. If a car has stopped, it will require a driving Force to move it, conversely, to stop the car it will require a braking Force contrary to the direction of motion. The unit of measurement of Force in the International System is the Newton *(N)*.
The product of the intensity of Force, in the direction of displacement, multiplied by the displacement of the body is defined as the **Work** of a Force. The unit of measurement is the Joule *(J)*.

$$L = F\,s \;\; [J]$$

Figure 25
Pos. 2: **Gravity**: the force that attracts a body toward the centre of the earth, or toward any other physical body having mass.
Pos. 3: **Equilibrium of Forces**: an object can be acted upon by two or more Forces at the same time. If the size and direction of the Forces acting on it are exactly balanced, then there is no net Force acting on the object and the object is said to be in equilibrium. In equilibrium an object at rest will stay at rest, and an object in motion will stay in motion. The Force exerted to withhold a body is equal and opposite to its weight.

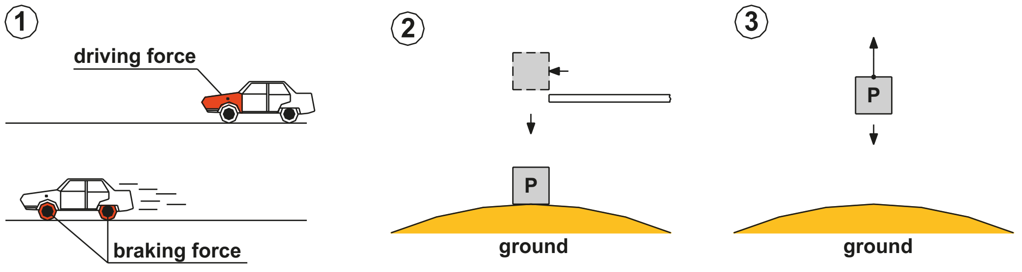


Fig. 25

Figure 26
Pos. 4: **Average velocity ν**: is the relationship between the distance S travelled by a body and its relative time interval Δ_t. The unit of measurement is *m/s*.

$$\nu = S/t\ [m/s]$$

Figure 26
Pos. 5: **Average acceleration**: is the relationship between the change of speed Δν and the time interval *t* in which such variation occurs. The unit of measurement is m/s^2.

$$a = (V - Vo)/t\ [m/s^2]$$

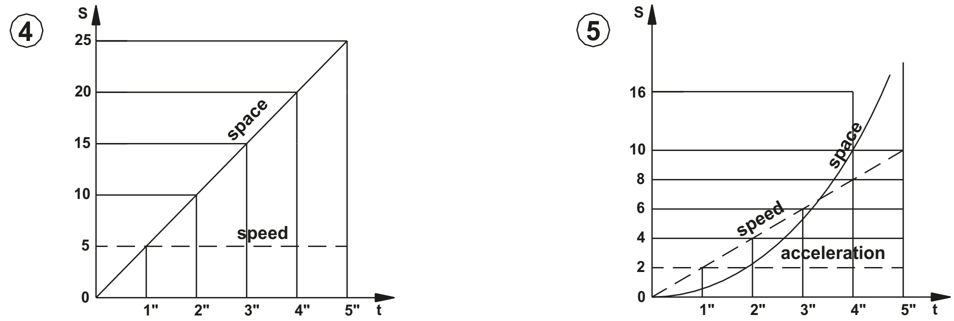


Fig. 26

Figure 27
Pos. 6: **Relationship between Mass and Weight**: the mass *m* of a body is constant regardless of its position in space and is measured in *Kg*. The weight corresponds to the mass under the effect of the acceleration of gravity and is measured in *N*. The value of the weight *P* is directly proportional to the mass *m*.

$$P = m\,g \qquad \text{where} \qquad g = 9{,}81\ [N/Kg]$$

Figure 27
Pos. 7: **Relationship between Force and Mass**: if a body is positioned in space in a state of rest or uniform motion, and a Force is applied continuously and constantly F_m, it will move with a uniformly accelerated motion in the direction of the Force. The value of this Force is given by the product of the mass *m* by the acceleration *a*.

$$F_m = m\,a\ [N]$$

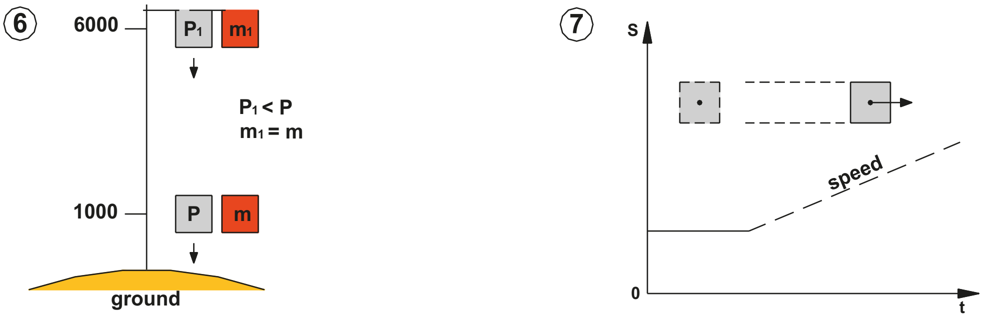


Fig. 27

Figure 28
Pos. 8: **Kinetic energy**: is the energy of an object, which it possesses due to its motion.
The kinetic energy is measured in Joules:

$$E = \frac{1}{2}\,m\,\nu^2\ [J]$$

A moving car has energy. Removing the driving Force behind the movement, the car will still continue until stopped by friction resistance.

Figure 28

Pos. 9: **Sliding friction**: is the resistant Force that occurs between two flat surfaces that remain in contact while sliding relative to one another.
Its value depends on the material of the bodies in contact, the surface finish of the surfaces, the possible lubrication and the Force with which the two surfaces are in contact with each other. The sliding friction does not depend on the area of the contact surface.There are two types of sliding friction:
a) **Static friction**, the friction between two solid objects that are not moving relative to each other.
b) **Kinetic (dynamic) friction**, occurs when two objects are moving relative to each other and rub together.
The coefficient of static friction is usually higher than the coefficient of kinetic friction.
A body of weight *P* is placed on a surface, the resistant Force due to sliding friction is:

$$F = c * P \ [N]$$

where *c* is a numerical coefficient defined "**coefficient of friction**" which takes into account the nature of the materials of the two surfaces in contact and the possible presence of a lubricant.

Figure 28

Pos. 10: **Rolling friction**: is the Force resisting the motion when a body rolls on a surface. It is proportional to the pressure applied to the surface of contact to the bodies. It is inversely proportional to the length of the rolling body and its radius. If the length is increased, the body is subject to less friction because the unit pressure decreases. If the radius is increased, the Force is distributed over a greater surface area.
A rounded body (wheel) of weight *P* is supported on a floor, the Force due to friction resistant rolling applies:

$$F = \frac{b\,P}{r} \ [N]$$

where *b is the* "**rolling friction coefficient**" and *r* is the radius of the rolling body.

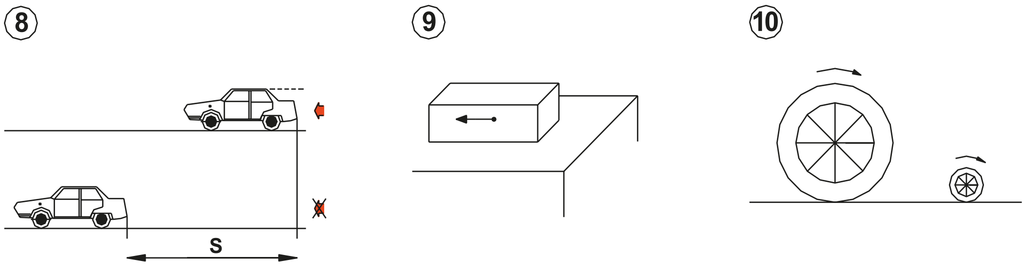


Fig. 28

Calculation of the Force required for the movement of a body in different directions and with different types of friction.

Body mass	$m = 50\ Kg$
Distance to cover horizontally	$S = 2\ m$
Required time	$t = 5\ s$
Coeff. of static friction	$c_1 = 0{,}02$
Coeff. of sliding friction dynamic	$c_2 = 0{,}01$
Coeff. of rolling friction	$b = 0{,}002\ m$

Calculation of the weight of the body:

$$P = m * g \qquad P = 50\ [Kg] * 9081\ [m/s^2] \qquad P \cong \mathbf{490\ N}$$

To rotate the body movement in a vertical direction, a driving Force greater than the vertical weight Force must be applied:

$$F_{mv} > P; \qquad F_{mv} > 490\ [N]$$

Static friction Force

$$F_{a1} = P_{c1} \qquad F_{a1} = 490\,[N] * 0{,}02 \qquad F_{a1} \cong \mathbf{9{,}8\ N}$$

Kinetic friction

$$F_{a2} = P_{c2} \qquad F_{a2} = 490\,[N] * 0{,}01 \qquad F_{a2} \cong \mathbf{4{,}9\ N}$$

Acceleration

$$a = \frac{2S}{t^2} \qquad \frac{2 * 2\,[m]}{5\,[s^2]} \qquad \frac{4\,[m]}{25\,[s^2]} \qquad a = \mathbf{0{,}16\ m/s^2}$$

To be able to move the body with an acceleration equal to 0,16 $[m/s^2]$ it is necessary for the resultant horizontal Force to be:

$$F_{Ro} = m * a \qquad 50\,[Kg] * 0{,}16\,[N/s^2] \qquad F_{Ro} = \mathbf{8\ N}$$

The horizontal driving Force applied will be:

$$F_{mo} = F_{Ro} + F_{a2} \qquad 8\,[N] + 4{,}9\,[N] \qquad F_{mo} = \mathbf{12{,}9\ N}$$

The obvious difference in the Forces between $F_{m\mathbf{v}}$ and F_{mo} is due to the vertical equilibrium condition, the Force F_e must oppose the Force of gravity acting downwards on the body, this is not a factor in the horizontal condition, as the supporting plane provides an equal and opposite Force to support the weight of the body.

Velocity

$$\mathbf{v} = a * t \qquad 0{,}16\,[m/s^2] * 5\,[s] \qquad \mathbf{v = 0{,}80\ m/s}$$

The work required to move the body is:

$$L = F_{mo} * S \qquad 12{,}9\,[N] * 2\,[m] \qquad L = \mathbf{25{,}8\ J}$$

A part of it will be dissipated to overcome the friction Force and a part will be transferred to the body in the form of kinetic energy:

$$E = \frac{1}{2}\ m * \mathbf{v}^2 \qquad \frac{1}{2}\ 50\,[Kg] * 0{,}8^2\,[m/s^2] \qquad E = \mathbf{16\ J}$$

Assuming that the body is a wheel of radius *r* equal to 500 *mm*, the rolling friction Force would be:

$$F_{mo} = \frac{P\,b}{r} \qquad \frac{490\,[N] * 0{,}002\,[m]}{0{,}5\,[m]} \qquad F_{a\mathbf{v}} \cong \mathbf{1{,}96\ N}$$

And the horizontal driving Force:

$$F_{mo} = F_{Ro} + F_{a\mathbf{v}} \qquad 8\,[N] + 1{,}96\,[N] \qquad F_{mo} = \mathbf{9{,}96\ N}$$

Magnetism and electromagnetism

Magnetism is the Force of attraction possessed by a mineral called "magnetite or natural magnet" to ferrous materials.

Figure 29
Pos. 1: when mild (low carbon) steel - often referred to as "iron", comes into contact with a magnet, or within the radius of its magnetic action, it becomes a magnet itself, however it loses this property when no longer within the radius of the permanent magnet.
On account of this property the mild steel is defined as an "artificial temporary magnet". Hard (high carbon) steel, once magnetized will retain this property for a long time, and is therefore defined as "permanent artificial magnet."
Pos. 2: the magnetic attraction is not equal on all points of the magnet; it is at maximum at the two ends and decreases towards the centre. You can verify this experimentally by bringing a natural or permanent magnet into contact with iron filings; you will observe the fillings are only attracted to the ends of the magnet. The ends of the magnet are referred to magnetic poles. All magnets have two **poles**.
Pos. 3: suspend a thread through a magnetic needle, so that, regardless of location, the needle will orient towards the **magnetic North**. By convention, the end of the needle that points to magnetic **North** is the **North Pole**, the other end is the **South Pole**.
Pos. 4: bringing the North Pole of a magnet close to another North Pole, the two will repel each other, likewise will two South Poles, and conversely with the North and South together, the two opposite poles attract.
Pos. 5: the area of attraction is called the **magnetic field**.

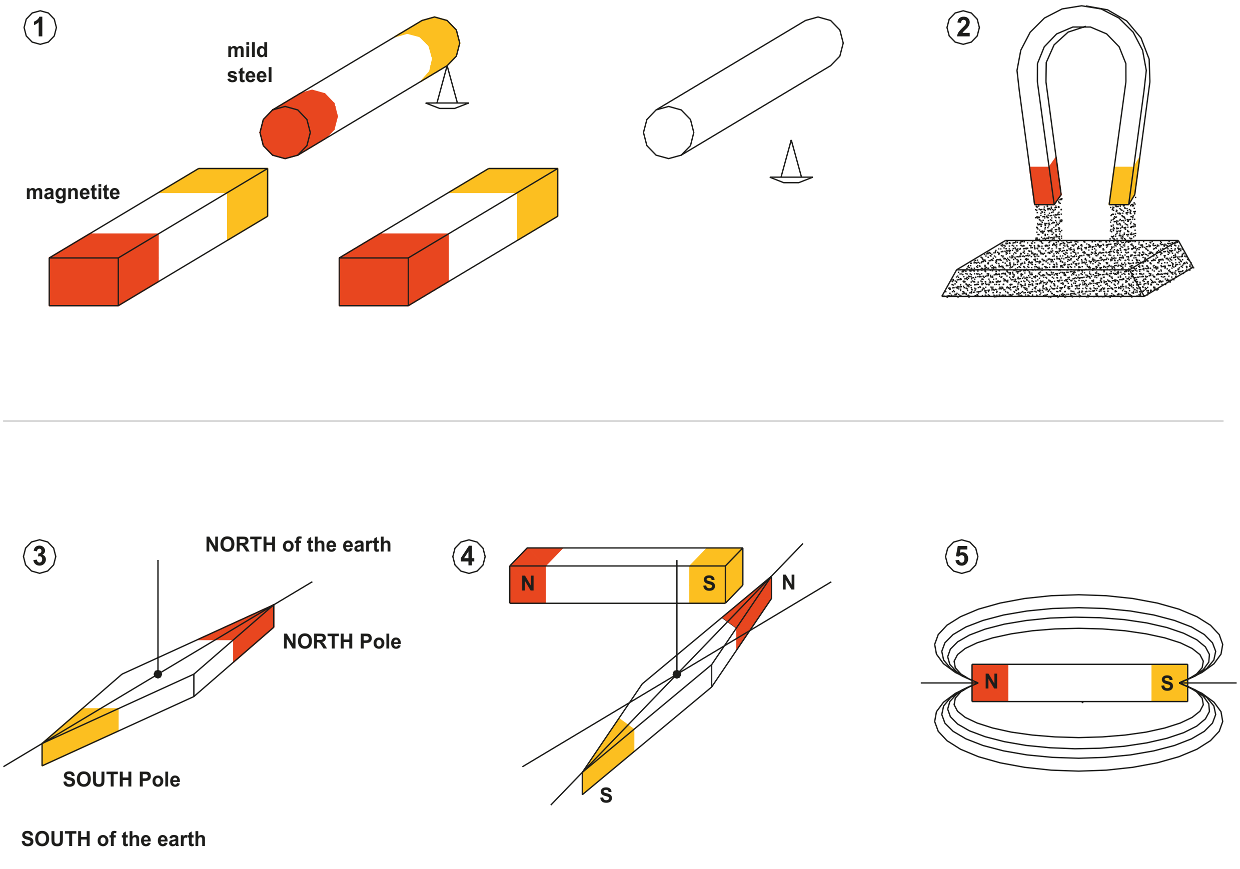


Fig. 29

Electromagnetism
An electric current passing through a conductor induces a magnetic field identical to that produced by a magnet. Electrons are minute charges of electricity, and are present in all bodies; their ability to move along the conductors is defined as **electrical current**.

Figure 30
Pos. 6: a card is sprinkled with iron filings and a copper wire is passed through the centre. Applying electricity to the copper wire, we observe the filings are arranged in concentric lines around the wire, identifying lines of Force and establishing the evidence of a magnetic field.

Figure 30

Pos. 7: the magnetic field demonstrated in Pos. 6. can be increased, i.e. the lines of Force may become denser if the wire is spirally wound to form a coil or "solenoid". Their behaviour is similar to that observed of magnets in Figure 29 (Pos. 5).

Pos. 8: if a piece of mild steel is introduced into the energized coil, it will become magnetized and acquires the ability to attract other bodies making it an electromagnet. If the body in the range of the magnetic field were fixed, the steel core would be moving. This device is used in many industrial applications because its magnetic property can be controlled. An indispensable feature of the device is that the nucleus is only magnetized when the coil is energized, the core must be of iron, as, in the absence of electricity, it loses the ability of attraction and the lines of force disappear.

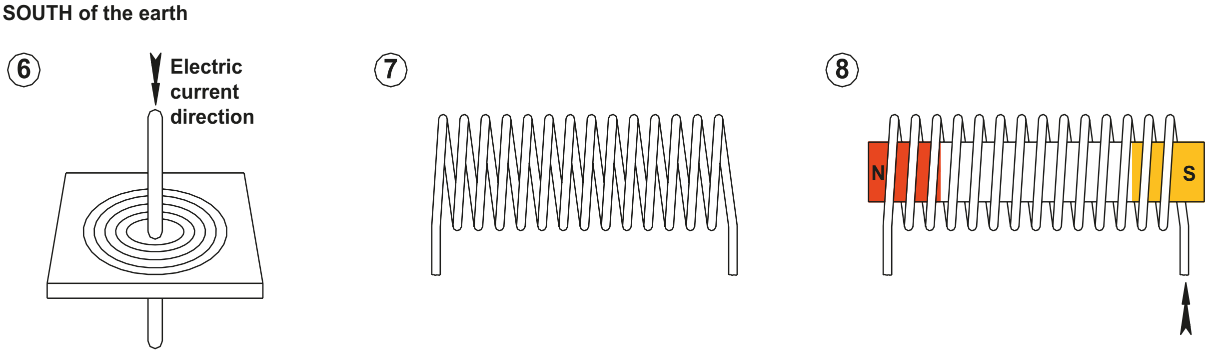


Fig. 30

CHAPTER 2

AIR PRODUCTION AND PREPARATION

Compressors

With a bicycle pump it is possible to raise the air pressure from atmospheric to a higher value, i.e. it is possible to compress and store the air within the bicycle tube to the pressure value necessary.
As discussed in the previous chapter on Physics, an increase in air pressure is a direct result of the reduction in the available container volume or an increase in the number of air molecules per given space.
The pumps producing compressed air according to this principle are often of the **volumetric compressor type**. They can be divided into two groups, **reciprocating** and **rotary** depending on the mechanism used to create a progressive reduction in the volume of air drawn into the pump inlet.
In this section we make a few brief observations on the fundamental characteristics of these machines.

Figure 1
Pos. 1: **Description and operation of a reciprocating compressor.**
The movement of the internal components is similar to that of a two-stroke petrol engine with the major difference being that the compressor "crankshaft" requires an input from a power source such as an electric motor.

a) as the piston descends it draws free air through the left inlet valve while the right remains closed.
b) as the piston is in the ascending phase, the left inlet valve closes, the right outlet valve opens when the pressure created by the piston is sufficient for overcoming the resistance, the now compressed air is sent to the tank where it is stored.

The external part of the sliding area of the piston is equipped with cooling fins to dissipate the temperature rise generated by air compression and friction resulting from the sliding of the pistons.
At the same pressure and flow rate of air to be stored, the final temperature may be be contained in the main stage by using **multistage compressors**. These use the following principle; air is drawn into the first stage chamber and compressed to an intermediate pressure. Before the air is passed to the second compression stage it is cooled. The cool air is then compressed further in the second stage thereupon reaching its final value.
Pos. 2: **Operation of the rotary vane compressor.**
This type of compressor is constructed from vanes,(blades) which are free to move radially, they are inserted in the grooves cut into a cylindrical body (rotor). This body rotates inside a circular seat; the axis of rotation of the body is moved laterally with respect to the theoretical axis of the circular seat, in this way a space is formed in which the blades may create sectors in which there is air.
When the rotor rotates by means of a power source, the blades are forced outward by centrifugal force and the air inlet is situated at the point where the volume between one blade and another is increasing. The outlet is situated where the volume is decreasing.
The suction or inlet phase occurs at point **A** and the volume increases until the blades reach point **D**. From point **E** to point **H** the volume is progressively reduced. Unlike the reciprocating compressor, the production of compressed air does not have alternating phases but is in continuous flow.
Cooling of the air can be achieved by the injection of oil, which must then be recovered, cooled and recycled.

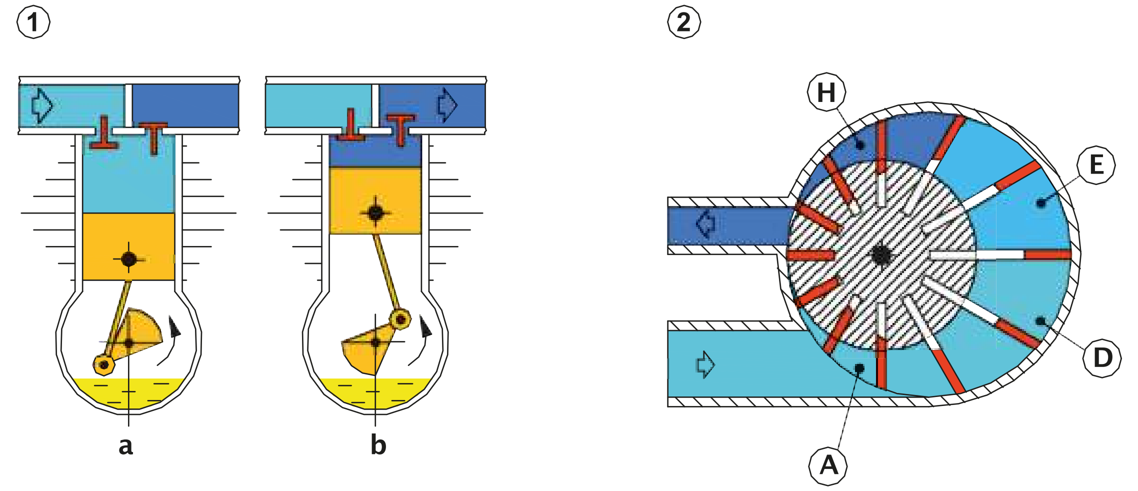


Fig. 1

Figure 2
Operation of the rotary screw compressors.
These units are formed by two worm screws positioned so that their surfaces are **almost** contacting.

a) The simplified front view shows the two screws with different profiles. The air is drawn in by the rotation of the two screws.
b) With the rotation of the two screws the air is drawn in, the space available for the air is then reduced thus initiating the compression phase and subsequent transmission to the outlet. This action occurs at every turn and every "corner" of the left screw.

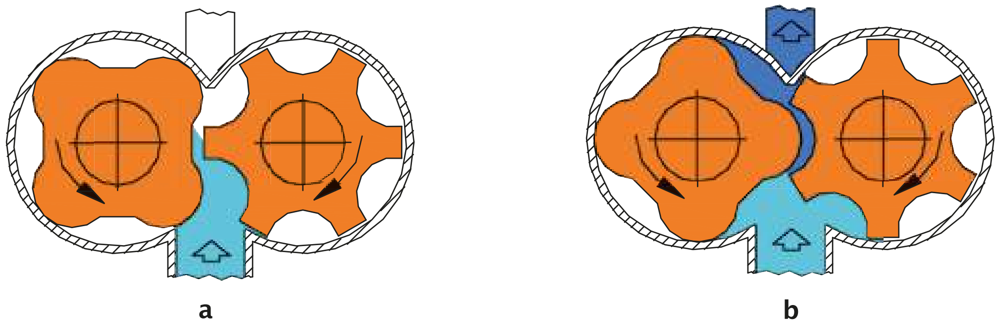


Fig. 2

Figure 3

Operation of the dynamic compressors.

These compressors are used to compress large quantities of air; they work on the principle based on the movement of air using impellers with blades. The kinetic energy that the air acquires is converted into pressure energy before it exits from the compressor.

Depending on the shape of the impeller the compressor is classified as **radial** or **axial**.

a) **Radial**
The first impeller receives free air and projects it radially towards a pipe connected to the inlet of the second impeller, and so forth. In each step there is an increase of pressure.

b) **Axial**
The movement of air maintains a direction which is parallel to the axis of the impeller.

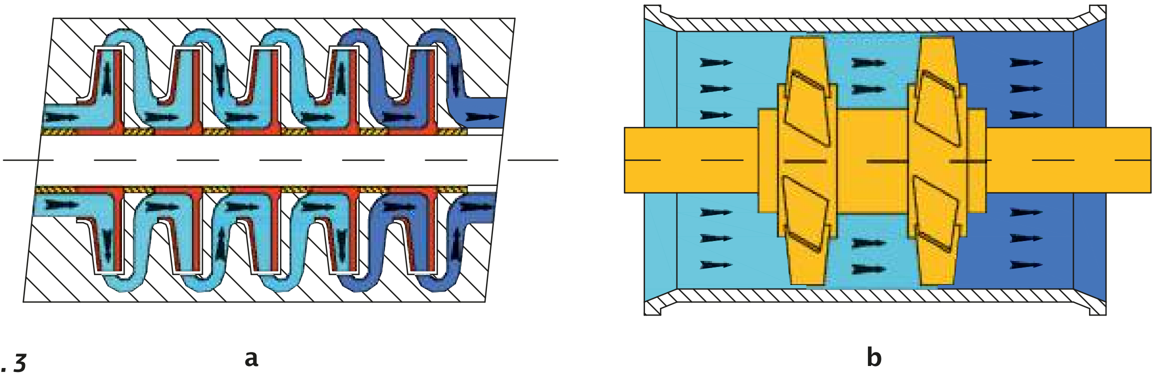


Fig. 3

Selecting your compressor.

The most important factor to define is the amount of air required (output capacity) which is calculated in Nm^3/h. This must correspond to the demands of the equipment to be operated.

The air consumption can be continuous or intermittent:
Continuous: machinery, equipment, utilities that are kept in continuous operation throughout the day. To this value, the sum of all leakage points from equipment as well as the air distribution system itself must be added.
Intermittent consumption: includes drills, grinders, screwdrivers etc.

The manufacturer of the latter type of equipment provides the air consumption as a function of pressure and time. Knowing the period in which they are used, it is possible to quantify the amount of air consumed in this unit of time. Regarding the cylinders and the respective connecting tubes, the calculation of the consumption will be discussed later. In general it is advisable to choose a compressor capable of providing a quantity of air, which is 50% greater than required, and to connect a tank downstream of the compressor itself.

From the compressor to the air receiver

The compressed air (C/A) cannot be used immediately, but must be treated to remove impurities such as solids, water vapour and oil mist. Adequate ventilation, ensuring the air entering the compressor is "clean" and good maintenance of the compressor, are simple measures, which can be taken to limit these impurities.

Figure 4
The air drawn into the compressor must pass through intermediate components before reaching the tank:

Suction/Intake filter: its function is to retain solid particles and the majority of impurities present in the air being passed into the compressor.

"After-cooler/Refrigerator": once the air is compressed, its temperature at the outlet can reach 200 °C.
The refrigerator cools the air, and as a result converts the water particles in the air from a gaseous to a liquid state. Normally, for the operation of cylinders, valves and pneumatic tools the air temperature must not exceed 40 °C.

Tank/Air receiver: this must be certified, subject to periodic inspection and testing by approved agencies, and equipped with a safety valve (which automatically discharges the air if the air pressure exceeds a certain value).

It has several functions:
- dampens the pulsations caused by the reciprocating type air compressors
- allows the temporary use of air at a quantity which exceeds the flow capacity of the compressor
- allows a reserve of compressed air in the event of a power failure
- ensures pressure stability in the network
- favours the storage of condensation

The Tank/air receiver normally has a number of ports or connection points:
- pressure gauge connection in the top cover
- C/A outlet screwed or flanged at the top
- C/A inlet, screwed or flanged at the bottom
- condensate discharge in the lower cover

Along the distribution line of the C/A, **condensation collectors**, are positioned; these are smaller containers, which collect the condensate, which is formed along the distribution line.

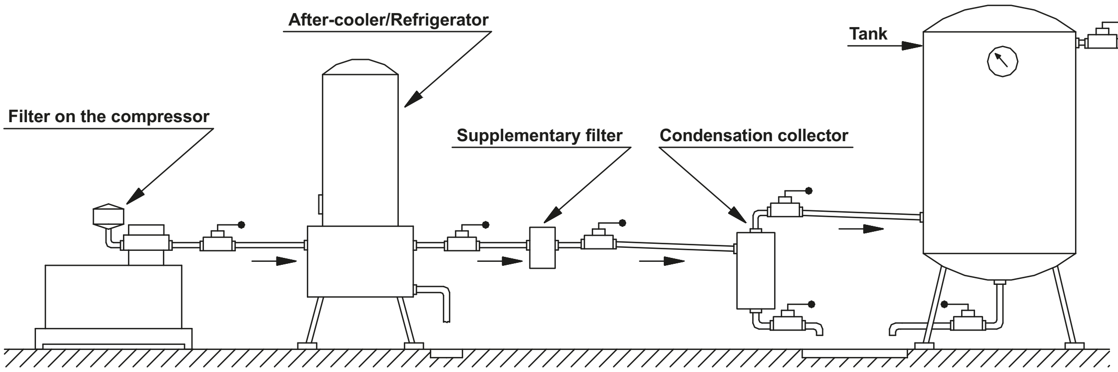


Fig. 4

Figure 5
Pos. 1: the air we breathe contains humidity from the evaporation of the world's surface water. This is particularly evident during the summer months when high humidity can make it difficult to breathe.

1 m^3 of free air at 25°C contains 23 g of water in the form of steam.
To obtain 1 m^3 of air at 6 bars pressure, 7 m^3 of free air must be compressed.

$$23 * 7 = 161 \text{ grams of water for every } m^3 \text{ of compressed air}$$

This water vapour, if not eliminated, will enter the distribution system, condense and then contaminate the equipment resulting in reduced working life and component failure. In the after-cooler, cooling the C/A can be done in two ways: by air or water.
The principle of operation of the refrigerator is based on the exchange of heat by conduction. The hot C/A passes through a cylinder in which there is a network of tubes in which water circulates. The air, when in contact with these pipes, decreases in temperature and this reduction in temperature reduces the ability of the air to hold water in its vapour form and a large proportion of the vapour condenses into the liquid. The accumulated water is channeled to the outlet.

Figure 5

Pos. 2: **the ball valves**, with a 90° rotation of the handle, are able to regulate the opening or closing of the passage, thus enabling maintenance work without the necessity of disconnecting the machine from the network.

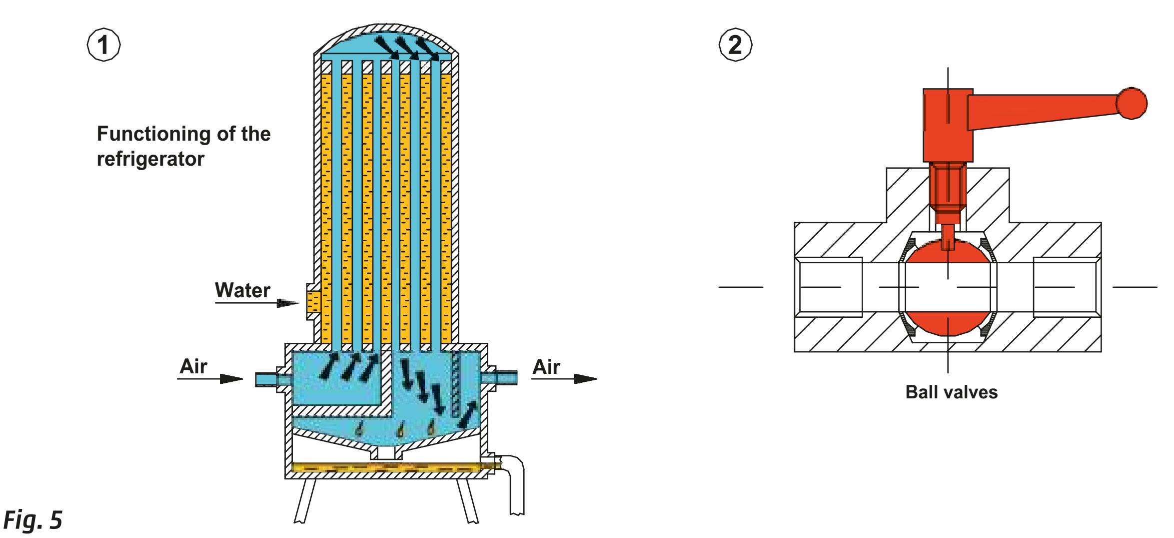


Fig. 5

From the receiver tank to the point of use

The piping network, which takes care of the distribution of the compressed air connecting the tank to the various user points of the air is defined as follows: the **primary and secondary network**.

Primary network.

This is the network, which runs horizontally from the receiver tank along the perimeter of the area to be served.

It can be constructed in a number of ways. This network is to be considered as an extension of the tank and dimensioned in such a way so as not to create either flow variations or pressure drops.

For proper installation and sizing of the primary network, the following should be considered: the pressure drop between the end points of the network and the request for compressed air which is determined by the number of user points, plus a safety margin.

Possible solutions for the installation of the primary network.

Figure 6

Pos. 1: **Open circuit**: this layout may be suitable when air is not drawn simultaneously along the whole of the network. On the contrary, there will be a continuous drop of the flow in the tubes, risking that the outlets at the end of the line will not receive an adequate pressure. A temporary network disconnection interrupts the supply to all downstream pipe-work.

Pos. 2: **Closed circuit**: the primary network starts and returns to the receiver tank having passed along the complete perimeter of the area to be served. The pipe used to construct the network is normally of the same section over the entire length. With this solution it is possible to have an even distribution of air pressure to each point of consumption, and it is also possible to isolate sections of the network.

Pos. 3: **Grid**: this is the most complex solution but also the most flexible, also the entire distribution network allows for an increase of the reserve quantity of air.

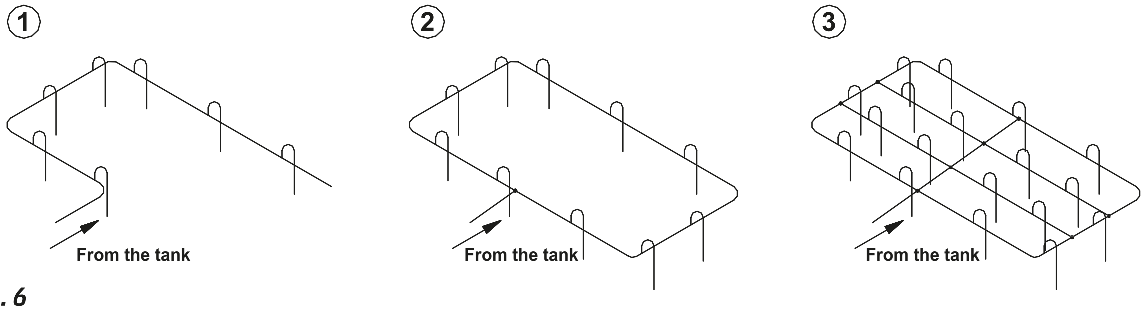


Fig. 6

Figure 7

In order to enable the condensate to flow in the pipes it is advisable to create an inclination of 1 *cm* for every 2 meters of pipe in the direction of airflow. This condensate is collected in special containers positioned at 40/50-meter intervals. The outlet of the compressed air is above the collector and it is from here the inclination starts. A condensate collector should be fitted at the end of the line.

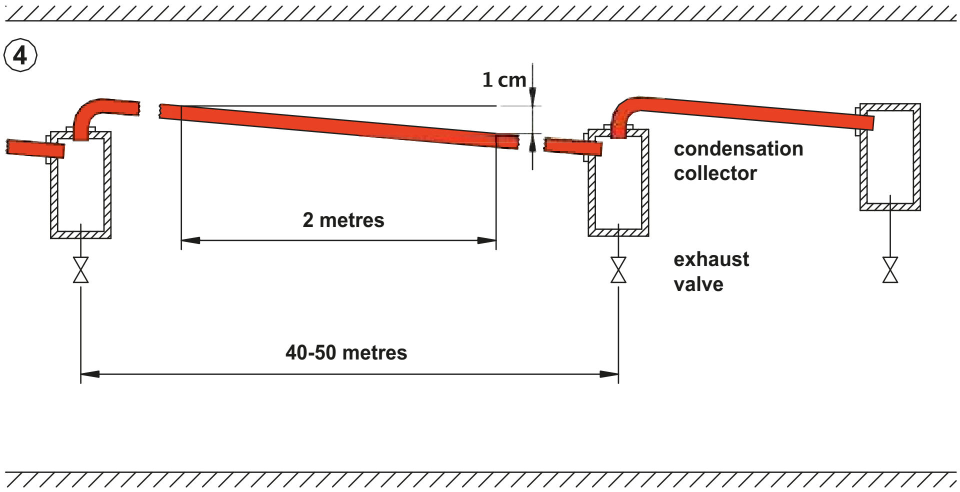


Fig. 7

Secondary network.

The secondary network describes the series of vertical pipes connecting the primary network to the various "user points" A condensate collector should be positioned at the end of each vertical line. On the secondary networks one or more connection points are installed to enable the air out-take for the various users.

Figure 8

Pos. 1: the junction between the main and secondary network is made by taking the air from the top part of the primary tube, in the case of both the welded pipes, as well as

Pos. 2: the water type pipes and fittings.

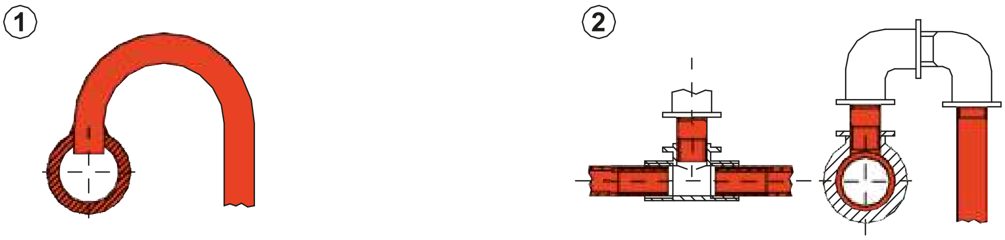


Fig. 8

Pipe size calculations

There are two methods, which can be used to regulate the correct internal diameter of the primary pipe-work.
Analytical: this accounts for the consumption at each point of use and the losses due to pressure drop for each length of pipe. This is an accurate and thorough method, but also time consuming.
Graphical: simple and practical, this method employs a Nomogram displaying each of the dimensions required to establish the correct size. The axis displaying pipe diameters is dual scaled in that it shows gas sizes in inches and millimetres, for the direct reading of the value:

How to use the Nomogram:

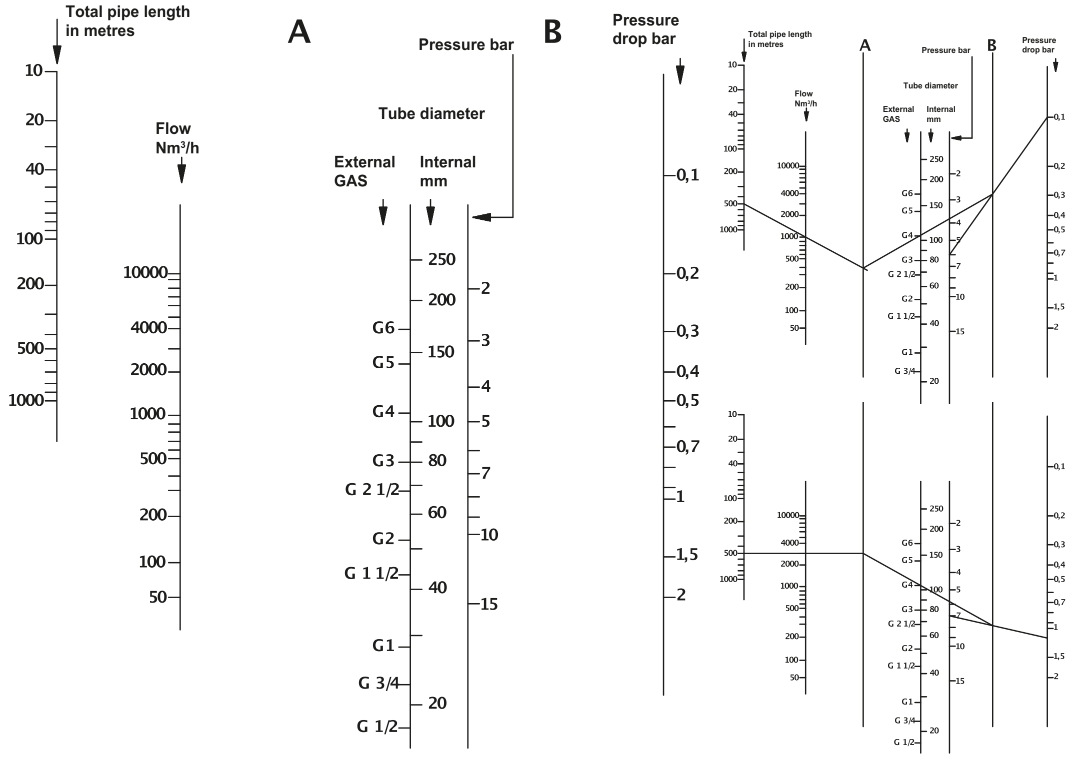


Fig. 9

Example 1: determine the internal diameter of a primary network, in a distribution network with the following characteristics:

total pipe length	500 *m*
maximum capacity	1000 *Nm³/h*
operating pressure	6 *bar*
pressure drop allowed Δ*p*	0,1 *bar*

Identify the value of length and flow rate on the respective axis.
Join the identified points and extend the line until the **A** axis.

Identify the value of the pressure and Δ*p*.
Join the two points with a line.

Join the two points established by the intersections on axis **A** and **B**. The required dimension will be established by the point where the line between axis **A** and axis **B** crosses the pipe size axis.

With these parameters, the value corresponds to the value **G4**.

Example 2: examine the pressure drop in the same network by replacing the compressor with another compressor with three times the capacity and with a pressure of 7 *bar*.

Identify the value of the length and the flow rate on their respective axes.
Join the identified points and extend the line until axis **A**.
Join the point on axis **A** with the **G4** point and extend the line to axis **B**.
Draw a line from the 7 *bar* point that passes through the intersection between axis **A** and axis **B** and extend it to the "pressure drop" axis.

With these parameters, Δ*p* is greater than 1 *bar*.

Note: the nomogram does not take into account the pressure drop of the fittings, valves, and any corners/curves included in the primary distribution network.

Treatment of compressed air

Characteristics of air

The presence of dust, moisture and oil vapours in the air contribute to the deposition of scale, which can create problems for the components as well as deterioration of the distribution network.

The most frequent problems are:

- Deterioration of the sealing elements in the pneumatic components and the consequent increase in friction.
- Increased maintenance costs of components and equipment.
- Increase in cycle time.
- Increased pressure drop and decrease in the final yield.

These impurities must be removed from the compressed air network, as the barriers installed at the compressor outlet are insufficient, therefore it is essential to fit a **filtering device** at the inlet points.

The filtering devices must ensure an optimal air purification minimizing the drop in pressure.

Characteristics of the fluid

The impurities in the air can be of different types, and depending on the application sector, different purification needs are required.
In our case, we consider only the elements indicated above, we don't take bacteriological contaminations into consideration as we are referring to components and filtration systems used in traditional industries.

The **International Standard ISO-DIN 8573-1** defines the characteristics of the fluid on the basis of the classes and the traditional impurities. The classification is made according to:

- Number of **solid particles** present in a m^3 of air relative to their diameter.
- Temperature at which, at constant pressure, the compressed air starts to condense the water vapour. Moisture is always present in the air in the form of **water vapour**, to be able to remove it, it is necessary to lower the temperature by using coolers or dryers.
- Maximum concentration of **oil**.

The table shows the maximum allowable values for all elements according to the defined class.
The quality of air required by components suited for a mining environment is not the same as the quality request from components designed for applications in the food or pharmaceutical sectors.

There are specific filtration systems for the different contaminants, and groups comprised of varying filtration elements with different characteristics can be made.

Class	**Maximum number of particles present in a m^3 according to their diameter**		
	0,1 µm < d ≤ 0,5 µm	0,5 µm < d ≤ 1 µm	*1 µm < d ≤ 5 µm*
1	≤ 20.000	≤ 400	≤ 10
2	≤ 400.000	≤ 6000	≤ 100
3		≤ 90.000	≤ 1000
4			≤ 10.000
5			≤ 100.000

Class	**Content of water**
	Temperature of water condensation
1	≤ *-70°*
2	≤ *-40°*
3	≤ *-20°*
4	≤ *+3°*
5	≤ *+7°*
6	≤*+10°*

Class	**Concentration of oil mg/m^3**
1	≤ 0,01
2	≤ 0,1
3	≤ 1
4	≤ 5
5	≤ 5

The filter

The filter element is the first part of the air treatment unit.

Figure 10
The compressed air passes into the filter inlet and reaches the deflector **A**. This component forces the air to swirl as it flows through the turbine type blades. The liquid and solid particles in the airstream, being heavier, are forced against the inner wall of the bowl **D** as a result of the centrifugal force. The baffle **C** separates the "turbulent" zone created by the centrifugal effect of the deflector, from the deposit zone. This prevents re-entry of the impurities into the airflow. The liquid and solid particles deposit on the base of the bowl **D**. The compressed air passes through the filter cartridge **B**, which retains the lighter impurities and then exits through the outlet. The filter cartridges are differentiated by the different degree of filtering expressed in Micron (μm), which corresponds to the maximum size of the particles to be filtered. If the filtering element is of 25 μm, means that the solid particles having a diameter greater than or equal to 25 microns will not pass, if the filtering element is of 5 micron, solid particles having a diameter greater than or equal to 5 μm will not pass through. The characteristic of the filter cartridge determines the class classification allocated in the ISO table, referring to solid particles.

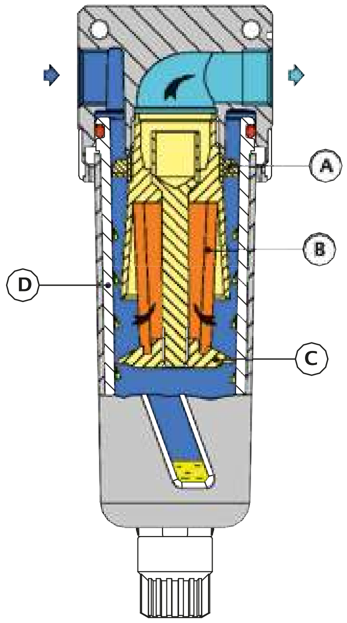


Fig. 10

The impurities, which are deposited at the base of bowl **D**, can be eliminated by means of the following types of drains.

Figure 11
Manual/Semiautomatic
Manual: by turning and pushing the drainage nut upwards its possible to open a passage from inside the bowl towards the atmosphere. This operation is facilitated by pressure inside the bowl.
Semiautomatic: while pressure is applied to the filter bowl, the outlet remains closed. When pressure is removed the spring opens the valve, venting any liquid in the bowl. This valve may also be operated manually by temporarily overriding the spring.

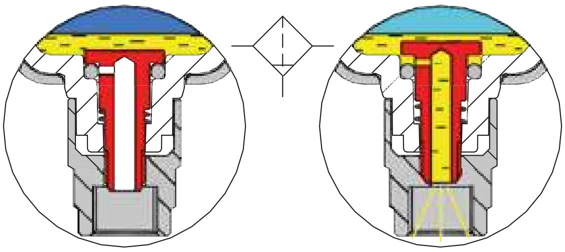


Fig. 11

Figure 12
Automatic depressurization
The "t-shaped plate" reacts to changes in pressure between its upper and lower side: whenever there is an air outflow, a slight pressure drop occurs on the upper side allowing an upward movement for a very short period of time so as to allow the opening of the exhaust and the expulsion of impurities.

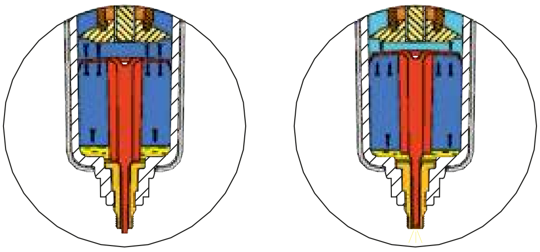


Fig. 12

Figure 13
The condensate deposited on the base of the bowl will rise a floater condensate that enables the opening of the drainage valve. As the level of liquid decreases, the floater closes the drainage valve.

The filtering element must be periodically cleaned or substituted.

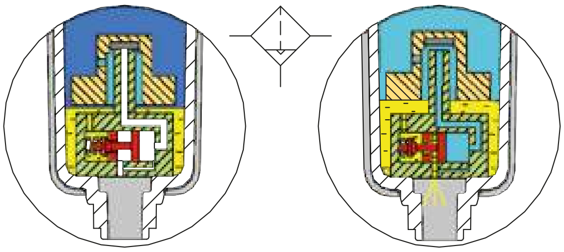


Fig. 13

Coalescing filters

To improve upon filtering characteristics offered by standard filters, **coalescing filters** are often used. These filters are suitable for removing the oil vapors in the compressor, which are not removed by the traditional systems. In these types of cylinders we have a different direction of flow and a different type of filter element.

Figure 14
Pos. 1: the air enters directly into the filtering element, which comprises several layers of different materials; the outer metal mesh restrains these layers in the presence of air-bursts arising from the initial input of compressed air entering the filter.
Pos. 2: to optimize the use of these filters they should be assembled downstream, i.e. positioned sequentially to other filter elements, hence the air undergoes an ever higher level of pre-filtering.

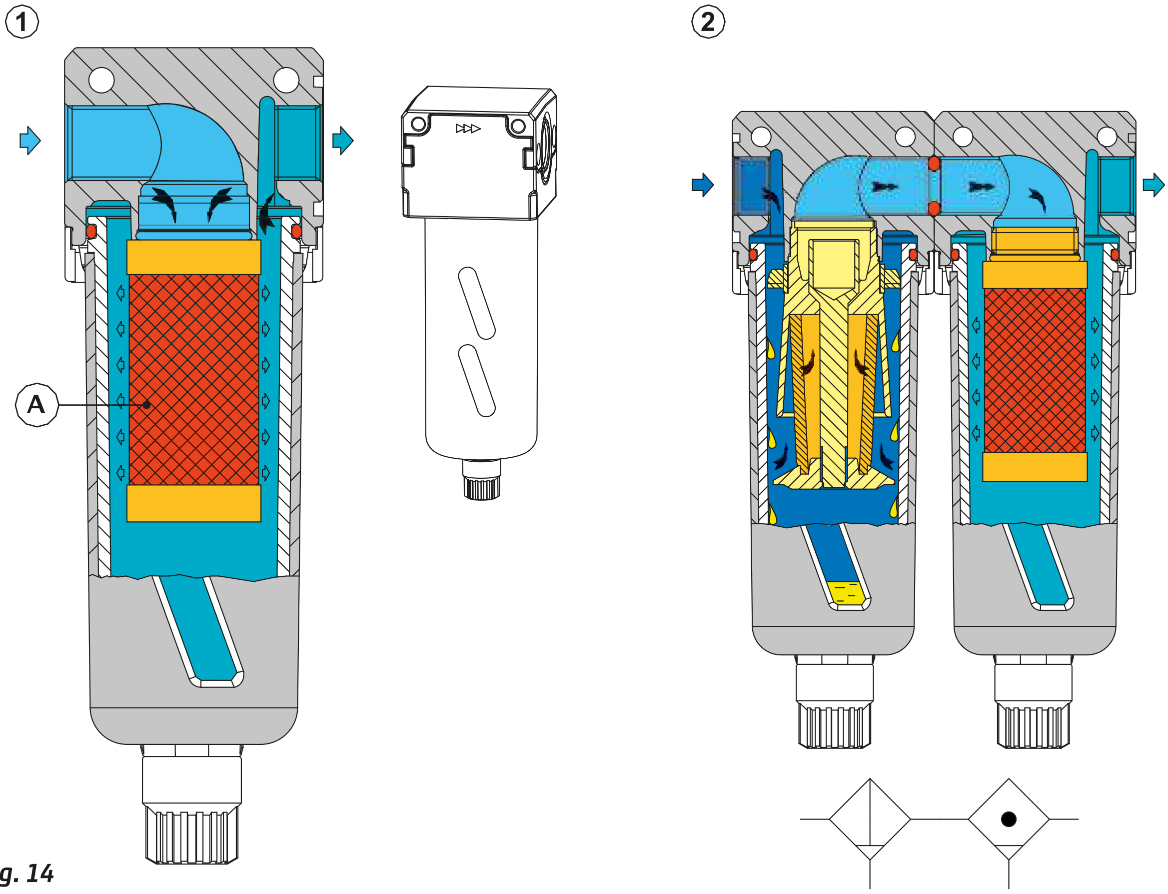


Fig. 14

These filters have cartridges with a level of filtration, which varies from manufacturer to manufacturer, and generally varies from 0,1 to 0,01 microns. The smaller the particles to be intercepted, the smaller the passage sections of the compressed air, and consequently the lower the flow rate.
As a result of the limited flow rate, these filters are not used to power the entire system of the machine, but only the most critical parts.

Pressure regulator

The pressure regulator, or pressure reducer, has the task of reducing the incoming pressure to a lower outlet pressure maintaining it at a steady value and independent from the variations in the incoming supply pressure or consumption.

Functional principles of the regulator

Figure 15
Pos. 1: the regulator has an incoming unregulated pressure at the inlet (from the left in blue) and is at rest position, the spring **B** has not yet been loaded by the "knob" **A**, the disk **C** therefore is not acting on the diaphragm **D**.
Pos. 2: represents the situation in which as a result of turning the knob **A**, the spring **B** becomes compressed, this in its turn acts on the disc **C**, pushing the diaphragm **D** downwards together with the plunger **H** which opens the poppet, enabling air to pass towards the outlet while the spring **F** is being compressed.
Pos. 3: as a consequence of the previous phase we have a flow of compressed air proportional to the spring load acting on the top of the diaphragm. The pressure reaches the desired value and the system returns to equilibrium. Through the channel **L** the secondary pressure acts on the underside of the diaphragm and in this way equalizes the force applied by the spring **B**. The plunger **H** will move upwards, with the help of the spring **F** and will close the main airflow. The system remains in this position as long as there is no consumption of compressed air.
Pos. 4: the secondary pressure decreases as a result of the compressed air being used, the force that acts under the membrane **D** is reduced as a result of this pressure drop, the spring **B**, whose load is constant, pushes both the disc **C** and therefore also the diaphragm **D** downwards together with the plunger **H** which re-opens the poppet, allowing air to pass towards the outlet.
Pos. 5: if we encounter an overload of pressure on the secondary side (secondary pressure higher than value adjusted by the spring **B**), this pressure reaches the underside of the diaphragm **D** through the channel **L**, lifting it upwards. The plunger **H**, thanks to the spring **F**, closes the passage towards the outlet, the upwards deformation of the membrane permits the opening of the channel **E** and the excess air pressure exits from the regulator through the relieving hole **M**.
This function is called **relieving** and intervenes also in the discharge phase of the system.
The relieving function is not present on hydraulic systems.

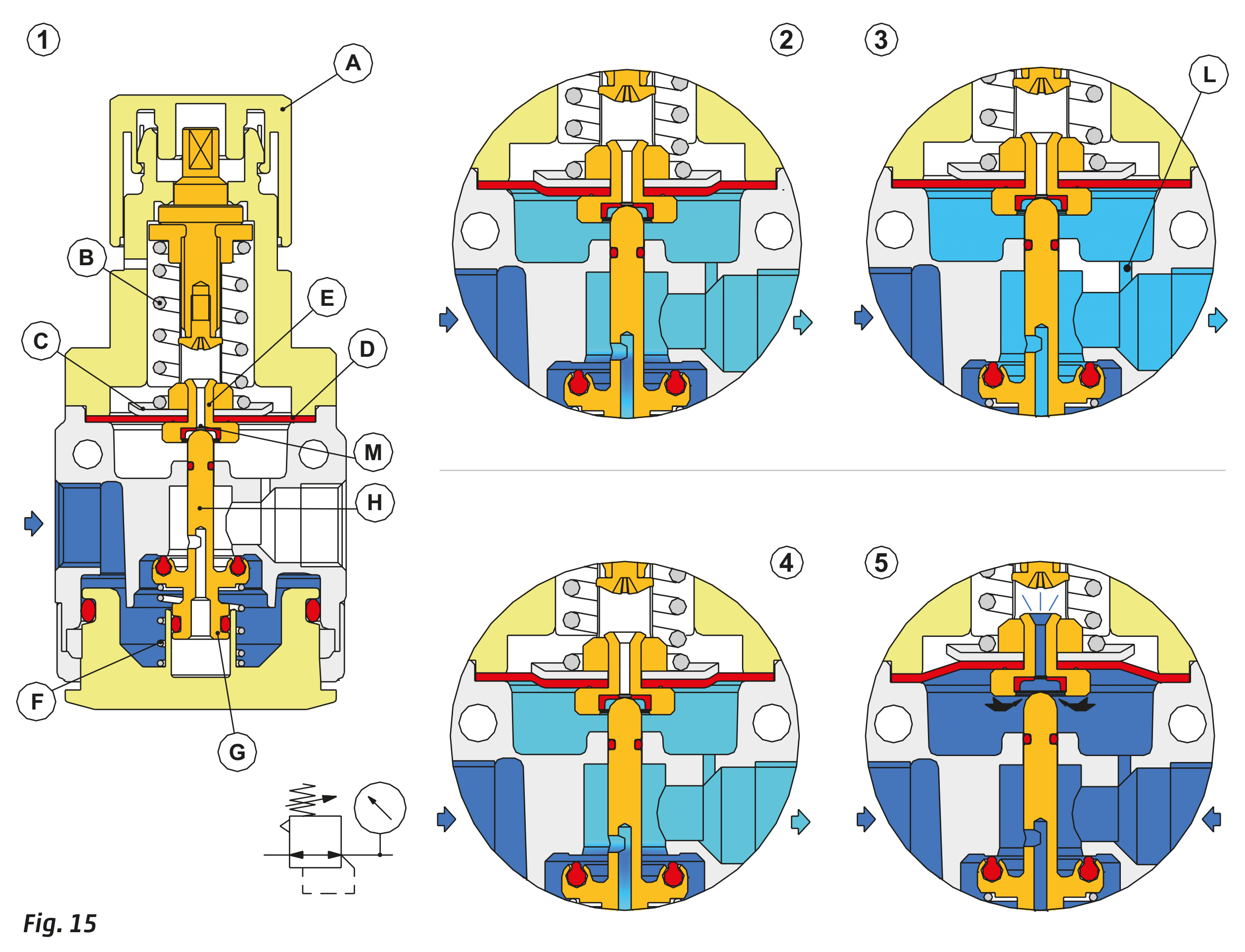


Fig. 15

To improve the regulation accuracy, the regulators are available with different springs **B** to better adapt to different pressure ranges. The pressure regulator can be integrated within a single body together with a filter element. This configuration is called the "Filter Regulator".

Isolation valves

These are valves, which can be, added to the air treatment units as modules and have a characteristically high flow rate as they feed the air distribution system. Their main task is to feed and exhaust the compressed air system or part of system to which they are installed. They are 3/2-way valves and can exhibit various types of commands.

Figure 16
Pos. 1: at rest position the spring **B** raises the spool **A** upwards, the outlet port 2 is connected with the exhaust port 3 and the inlet 1 is closed.
Pos. 2: energizing the solenoid creates an air passage which, by acting on the piston, moves the spool **A** downwards, allowing the passage of the compressed air from inlet 1 towards outlet 2, while the exhaust port 3 closes. The spring **B** is now compressed. When the command signal is interrupted, the pilot air acting on the piston exhausts and the spool is repositioned in the resting state with help from the spring **B**.

Below are the different command types:

Figure 16
Pos. 3: electric
Pos. 4: pneumatic
Pos. 5: manual (Lockable)

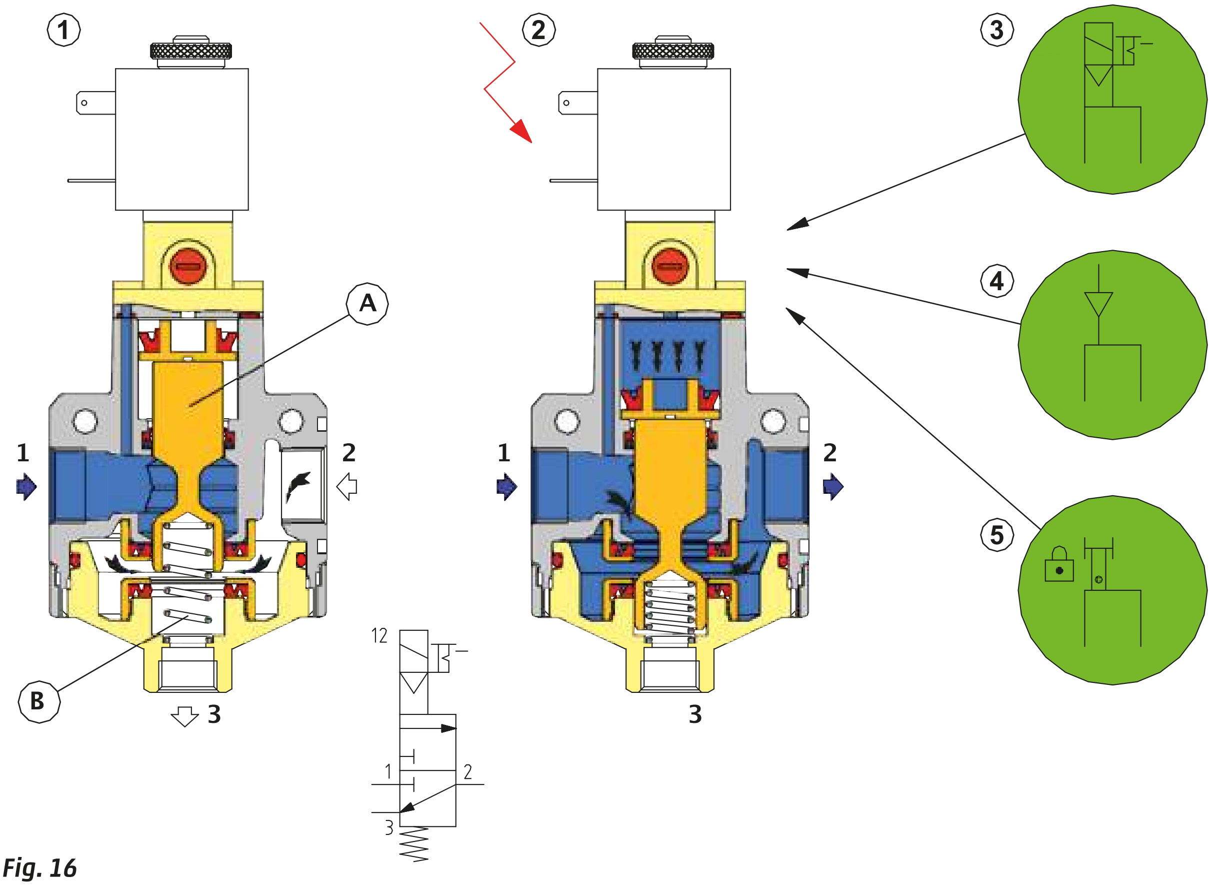


Fig. 16

In the manual version, the valve is the bi-stable type (push/pull knob). This is equipped with a hole, allowing the insertion of a lock so the valve can be locked in a closed position (maintenance mode). With the valve in this position the operators are able to carry out maintenance and other work on the system without risk.

When the valve is in rest position, the compressed air system is normally exhausted and all cylinder chambers are connected to the atmosphere. With the activation of this valve a rapid pressurization occurs on the system which could lead to sudden and uncontrolled movements of the piston/piston rods of the cylinders which could cause damage to the machine structure or even injure operators in close contact with the system To prevent this, a so-called soft start valve can be added to the isolation valve. We examine soft start valves in further detail in the following paragraphs.

The soft start valve

As indicated in the isolation valves section, in the absence of pressure, the piston rod/piston inside the cylinder's chambers may be in any position along the stroke and not necessarily at the end of the cycle position. This could occur because of the assembly position, for example when mounted in a vertical position or due to the action of a worker. With the pressurization of the system, the flow of air immediately fills the chambers of the cylinders and generates a sudden and uncontrolled movement of the rod/piston. This movement is uncontrolled as the chamber opposite to the movement is at atmospheric pressure and restricts the possibility of adjusting the speed, a situation that could cause damage, and not only structural damage.

To resolve these problems, the soft start valves are used.

Figure 17
Pos. 1: the soft start valve has no incoming compressed air.
Pos. 2: by activating the isolation valve, the pressure reaches the inlet of the soft start valve, the plunger **C** remains in closed position, as it is pushed upwards by the pressure and by the spring force **D**.
The sphere (illustrated in A) raises and closes the passage. Through the circular crown we find the sphere which has the function of an unidirectional valve, the compressed air passes under the regulation screw (highlighted in illustration B) that reduces the flow directed to the system.
Pos. 3: due to the gradually incoming pressure, the speed of the piston rod/piston inside the cylinders is limited, this speed depends on the degree of opening of the regulation screw. After this movement, the value of the pressure tends to grow, eventually overcoming the resistance of the spring **D**, the plunger **C** moves downwards, allowing the entry of air with maximum flow capacity.
Pos. 4: when the air supply is interrupted, the plant is exhausted with full flow through the isolation valve as the plunger **C** is still down.
Pos. 5: the value of the downstream pressure falls, the spring **D** returns the plunger **C** upwards, that closes the full passage. The unidirectional valve shown in **A** allows the complete exhaust of the circuit.

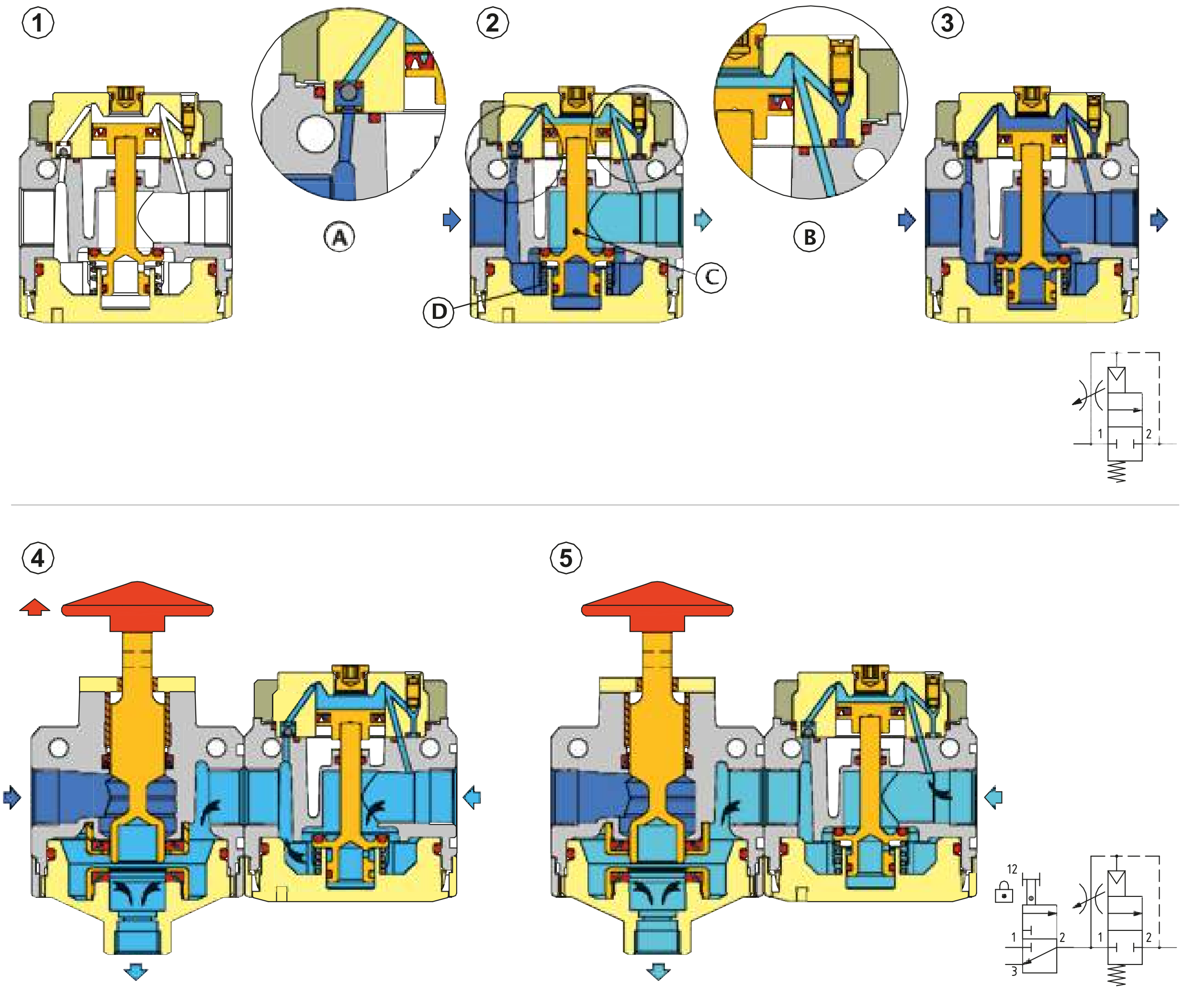


Fig. 17

Pressure regulator without compensation

In the previous paragraphs we illustrated the operation of the traditional pressure regulator. Always using the same pressure for all the work phases of the actuators implies an expenditure of electric energy by the compressor.
In the following paragraphs we will demonstrate that high pressure does not help to improve the speed of the piston rod/piston in the cylinders. In fact, differentiating the pressure in the actuators accordingly between the working and repositioning phase does not increase the cycle time, (in some cases it can even be reduced) and save energy.
When raising a load (with cylinder in a vertical position), a certain pressure which is adequate to perform this work is required, but the same pressure is likely to inflict damage during the descent where the force of the piston is added to the value of the load. The force of gravity by itself is sufficient to bring the load to the initial lower position.
Alternatively, another situation may arise where it may have the need to push or grip an object, in such a situation high pressure is unnecessary in the repositioning or release phase. Some types of valve islands have two pressure lines in order to differentiate the pressures between the working phase and the repositioning phase.
In other cases you can use pressure regulators without compensation, which are applicable between the control valve and cylinder. A traditional regulator may not be the best solution, in fact as analyzed in the illustrations - the **pressure regulator**; a compensation chamber is visible under the plunger **A**, which is connected to the outlet of the regulator through a small hole on the plunger. This compensation chamber allows for a better "response" i.e. better on the traditional applications where the flow has one direction, but not ideal for applications where the regulator is located between the valve and cylinder, (where the flow has two directions).

Figure 18
The regulator without compensation, the plunger **A** is different in the sense that the compensation chamber **B** uses a lip seal and the orifice is eliminated. Removing the supply pressure, as in the application where the regulator is mounted downstream from a directional valve, the exhaust air acts on the lip seal favouring the downward motion of the plunger which opens the passage towards the outlet, in this way it has a higher flow rate than a traditional system. The symbol representing this function is a standard regulator with a non-return valve.

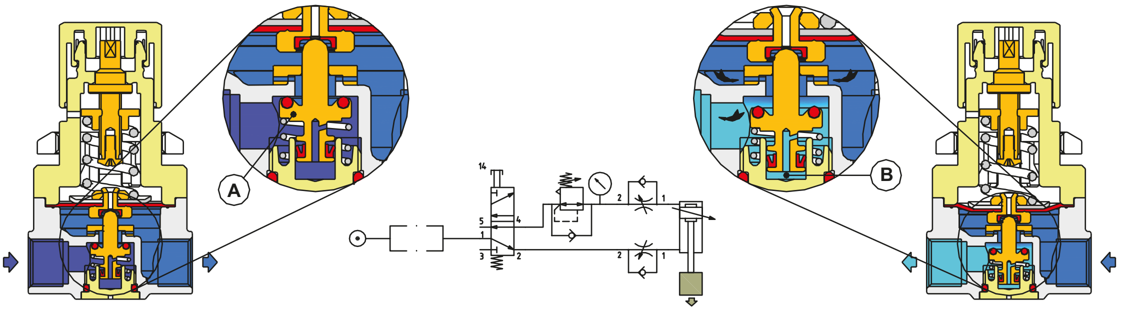


Fig. 18

Relief valve

In some applications you may have the need to maintain a constant pressure in a volume such as the chamber of a cylinder that has to be constantly pressurized to a defined value. In the event of a pressure increase, the excess quantity of air must be discharged into the atmosphere. With small volumes, as for example a small cylinder, it is possible to connect a pressure regulator with relieving. When the volume of air to be exhausted is large, the flow characteristics of the relieving may be insufficient.

Figure 19
This valve has the shape of a pressure regulator and it is mounted with the inlet connected to the free outlet in connection with the atmosphere. In this way the excess pressure generated in the cylinder chamber can be exhausted into the atmosphere. For example when we have a cylinder with the piston rod in a retracted position through a pneumatic spring realized by a pressure regulator, where the outlet of the pressure regulator is connected to the cylinder chamber through a non return valve (which prevents back flow through the regulator) and is branched with a relief valve. The relief valve is adjusted at a value slightly greater than the pressure regulator so that it only opens when there is an excess of pressure. By activating the push button the piston rod exits opposed by the pneumatic spring force. The pressure on the negative chamber tends to increase , but is held constant by the exhaust of the relief valve.

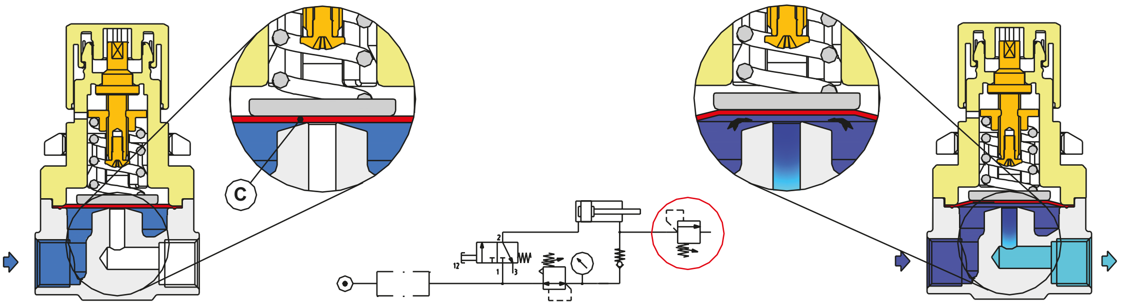


Fig. 19

Treatment of compressed air: the lubricator

All modern pneumatic components are initially lubricated with highly adhesive grease, which in most cases makes external lubrication unnecessary. Only in some situations, for example with high cylinder speeds or with high frequency of movement of the components, further lubrication can be advantageous.

Points to consider when using the lubricator:

- Once external lubrication is applied to the components, it must not be interrupted. The oils have a cleansing effect and remove the initial lubricating grease applied during the assembly phase of the component.
- To ensure compatibility with the seals, the lubricating oil indicated by the component manufacturer must be used.
- The correct quantity of oil generally ranges from 1 to 5 drops every 1000 litres of air. This value should not be exceeded.

In pneumatic systems the flow of air is used to distribute the lubricant (oil) to the components requiring it.
The device used is the “Oil Fog Lubricator”. It does so in the following way:

Figure 20
Pos. 1: the incoming air of the lubricator passes both through and outside the narrow passage **A**. The incoming pressure enters the bowl **C** containing the oil, acting on its surface, pushing it back into the tube and up to the sight glass in Pos. 2.
Pos. 2: the adjustment screw **D** allows the regulation of the oil quantity that falls on the narrow passage.
Pos. 3: part of the compressed air moving through the narrow passage increases its speed generating the **Venturi** effect that allows the suction of the previously dosed oil. When the oil enters the narrow passage, due to the impact with the high-speed airflow, it turns into an oil mist/fog, this allows it to be transported through the piping system.

The distance the oil mist flow travels depends on the amount of air required downstream and by the conformation of the pipes. 90-degree angles, distribution collectors and all elements that could create a barrier against the air flow and condensation of the nebulized oil are to be avoided.

Pos. 4 and **5**: the cap **C** acts on the valve in Pos. 5, which, being open, allows the pressurization of the bowl containing the oil. Removing the cap **C** while the system is in action (pressurized), the valve closes the airflow to the bowl and the remaining pressure in the bowl is released into the atmosphere. In these conditions and with **air still in the system**, it’s possible to remove the bowl from the lubricator and refill it with oil. Repositioning the bowl and then the cap **C**, the bowl is re pressurized and the lubrication is resumed.
Pos. 6: the sphere, as shown in the highlighted illustration, prevents oil from returning into the bowl each time the air consumption stops; the oil remaining above the sphere and in the pipe is immediately available for use when the air consumption resumes.

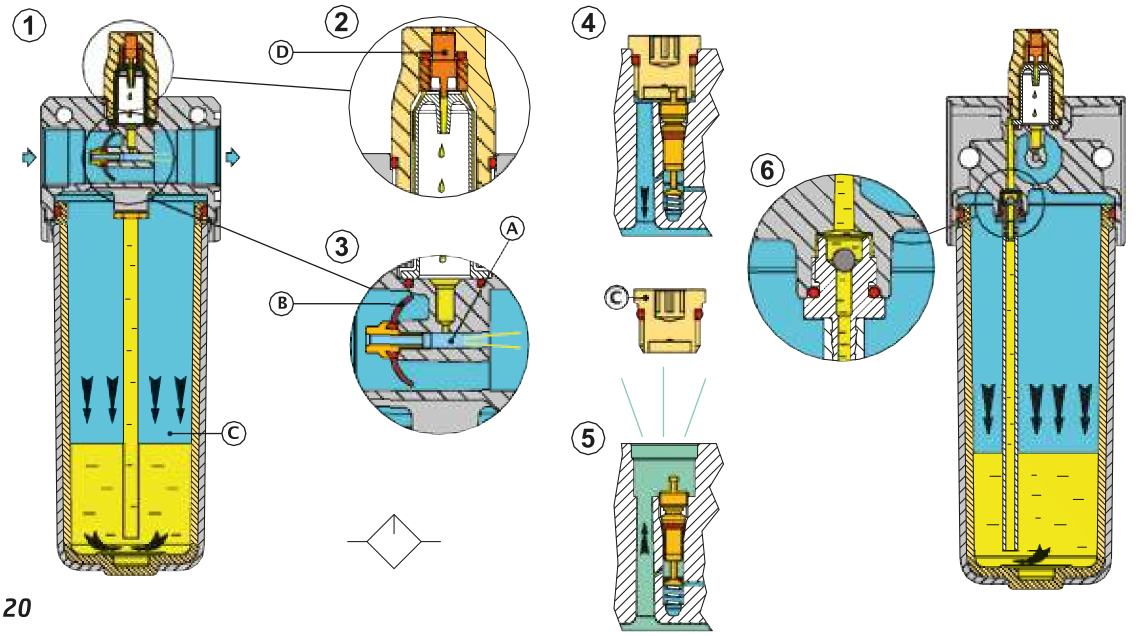


Fig. 20

One potential problem with using external lubrication is that the air, having been used in the pneumatic equipment, is exhausted into atmosphere. This exhausted air also contains oil particles which remain suspended in the working environment and which may damage people’s respiratory systems or contaminate the finished product (critical in food and pharmaceutical applications). It is therefore advisable not to exceed the quantity of oil during lubrication and above all to pass the valve outlets through appropriate filters, which can reduce this effect.
If no information on the type of oil to be used is provided, it is advised to use oil for lubrication systems, which generally fall into the class ISO VG 32. Modern technology tends to limit the use of oil by producing components, which can operate with non-lubricated air.

CHAPTER 3
CYLINDERS

Principles of cylinder operation

The pneumatic cylinder is a "motor" in the sense that it is capable of converting energy into a force. The energy to be converted is supplied in the form of compressed air (C/A).

Figure 1
The principle behind this operation is the opposite to that of a bicycle pump, where manual effort is expended to move the piston thereby compressing the atmospheric air to increase the pressure in the tyre. In the cylinder however, the pressure of the compressed air acting on the piston surface generates a force that initiates its movement, on the condition that the air contained in the opposite chamber is able to exhaust.

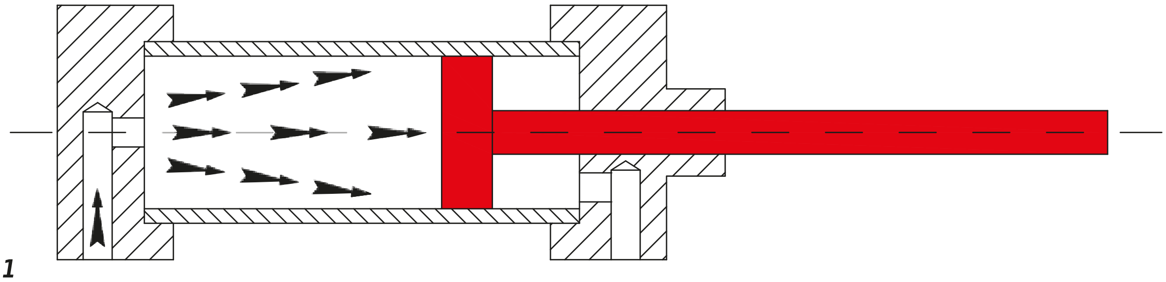


Fig. 1

While air pressure is applied to one side of a piston, an effective seal is necessary to prevent air passing through to the opposite chamber, otherwise there will be a loss of pressure and the force developed by the piston will be reduced.

Figure 2
Pos. 1 and **2:** the rear surface of the piston P_1 closes the air inlet hole. A ring separates the rear surface of the piston P_2 and the hole. With the same overall dimensions of the cylinder the best yield for the starting phase of the cylinder is obtained with the example in Pos. 2. The surface on which the compressed air acts is much greater than that in Pos. 1.
As defined by **Pascal**'s, principle, the pistons P_1 and P_2 are propelled by a thrust force:

$$F = p * S \qquad S = \frac{\pi * D^2}{4}$$

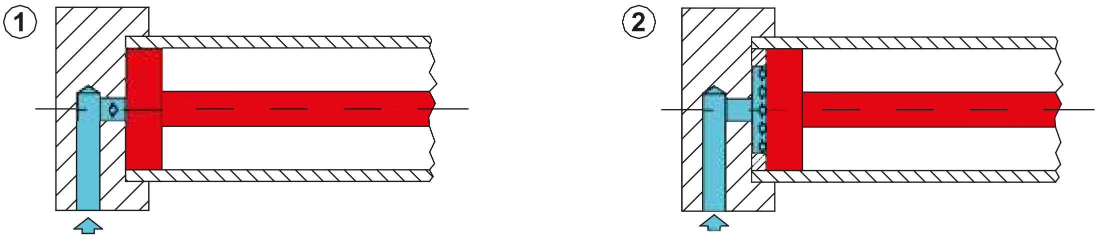


Fig. 2

Figure 3
Pos. 3 and **4:** at equal pressure, a quadratic proportionality between *S* and *F* exists, i.e. if the piston diameter is doubled then the thrust force quadruples, if the diameter is tripled the force increases by nine times, and so on. Given two pistons; P_3 with diameter D_3 = 20 *cm* and P_4 with diameter D_4 = 10 *cm* and a supply pressure *p* = 5 *bar*, we can calculate the thrust forces F_3 and F_4:

$$S_3 = \frac{\pi * D_3^2}{4} \qquad S_3 = \frac{3{,}14 * 20^2}{4} = \mathbf{314\ cm^2}$$

$$S_4 = \frac{\pi * D_4^2}{4} \qquad S_4 = \frac{3{,}14 * 10^2}{4} = \mathbf{78{,}5\ cm^2}$$

$$F_3 = p * S^3 \qquad F_3 = 50\,[N/cm^2] * 314\,[cm^2] \qquad F_3 = \mathbf{15700\ N}$$

$$F_4 = p * S^4 \qquad F_4 = 50\,[N/cm^2] * 78{,}5\,[cm^2] \qquad F_4 = \mathbf{3925\ N}$$

From the results it is clear that a diameter that is twice the size (D_3 is twice as large as D_4) generates a quadruple force (F_3 is four times larger than F_4). The conclusion we can draw from this is that a quadratic proportionality exists between diameter and force.

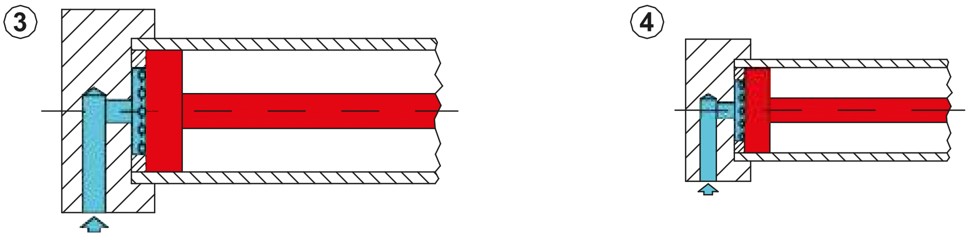


Fig. 3

Figure 4

Pos. 5 and **6:** with an equal surface area, the pressure p and the Force F are directly proportional, as one increases, the other decreases linearly.
In this example, pistons P_5 and P_6 have the same diameter $D = 20\ cm^2$, but are powered by different pressures $p_5 = 10\ bar$ and $p_6 = 5\ bar$.
We calculate the thrust forces F_5 and F_6.

	$S = \dfrac{\pi * D^2}{4}$	$S = \dfrac{3{,}14 * 20^2}{4} = \mathbf{314\ cm^2}$
$F_5 = p_5 * S$	$F_5 = 100\ [N/cm^2] * 314\ [cm^2]$	$F_5 = \mathbf{31400\ N}$
$F_6 = p_6 * S$	$F_6 = 50\ [N/cm^2] * 314\ [cm^2]$	$F_6 = \mathbf{15700\ N}$

In this case, we have established that a pressure, which is twice as great (acting on a surface of the same size), (p_5 is twice p_6) causes a force that is double, i.e. pressure and force are directly proportional.

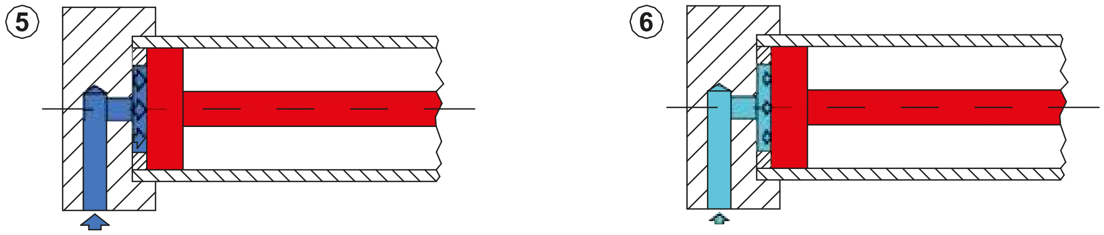


Fig. 4

Component parts and terminology

Figure 5

- **Tube/barrel**: is the part enclosed between the two end caps inside which the piston rod/piston entity runs; the inside diameter, or bore, is the decisive factor in the choice of the cylinder.
- **Piston**: Moves within the barrel, separating the chambers with seals; in some cases it integrates a magnetic ring for detecting its position. Its movement is linear.
- **Piston Rod**: is the metal shaft connected to the piston and extends outside the cylinder to transmit the force generated.
- **Front and rear end caps**: they ensure the mechanic and pneumatic sealing of the tube and allow the inlet connections and air exhaust. They can have adjusting screws for the end stroke cushioning and mounting holes for the mounting of the fixing elements (brackets) of the cylinder. The front-end cap integrates a guide bearing for the sliding of the piston rod.
- **Dead space**: this is the remaining space between the end cap and piston at the end of the stroke.
- **Positive chamber**: this is the space between the piston and the rear end cap. Its volume will vary depending on the position of the piston.
- **Negative Chamber**: this is the space between the piston and the front-end cap. Its volume will vary depending on the position of the piston.
- **Active chamber**: chamber under pressure.
- **Passive chamber**: it is the exhaust chamber.
- **Positive stroke**: the direction of the piston rod/piston as it extends from the body.
- **Negative stroke**: the direction of the piston rod/piston as it re-enters the body.
- **Effective thrust area**: the surface area of the piston facing the positive chamber. This corresponds to the internal section of the tube.
- **Effective pull area**: this is the surface on which the air exerts its pressure in the negative chamber. It is smaller than the Effective Thrust Area because of the presence of the piston rod.
- **Single-acting cylinder (S/A)**: is realized in such a way that the return of the piston rod/piston occurs via an internal spring. Usually air is applied to the positive chamber, driving the piston rod to its extended position. The return stroke is achieved by a spring in the negative chamber. The negative chamber is always connected to the atmosphere, and therefore never pressurized.
- **Double-acting cylinder:(D/A)**: is realized in such a way that the pressure can be exerted alternatively on both sides of the piston. The piston applies a force in each direction.

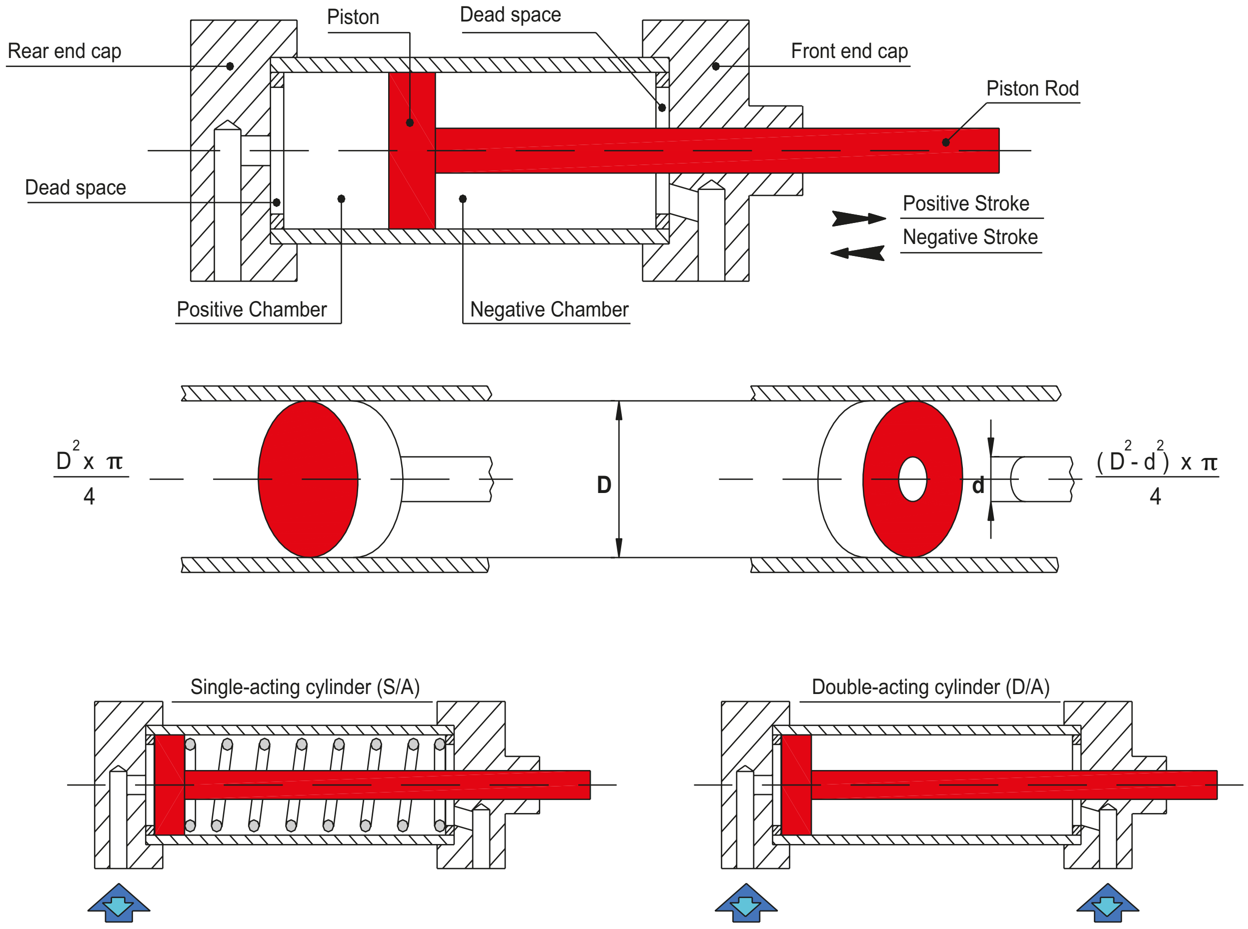


Fig. 5

Pressure differential in the two chambers of a double-acting cylinder

In a double acting cylinder with the two chambers in contact with the atmosphere, the piston rod/piston is free to move along the length of the stroke (in both directions) without any particular resistance.
We place the piston rod/piston against the front end cap, and we tightly close the air inlet on the opposite (rear) end cap and execute the negative stroke manually (by pushing the piston rod inwards). We realize we have to exert a force of increasing intensity to overcome the counterforce that is created in the positive (rear) chamber as a result of the reduction of the air volume and the consequent rise in pressure. This volume, not being able to exhaust, becomes an elastic obstacle preventing the piston from reaching the rear end cap. If we now release the piston, it almost returns to the starting point. Continuing with the operation, we realize we have to pull the rod with increasing Force due to the constant decrease of the volume of air in the negative chamber and the consequent increase in pressure. Repeating the operation and allowing the negative chamber contact with the outside through a small hole, we find the movement during resistance to be proportional to the diameter of the hole. With equal force applied, the smaller the diameter of the hole, the lower the speed obtainable.
The compressed air in the front chamber acts as a "brake" avoiding the piston rod/piston reaching uncontrolled speeds capable of causing damage to the structure or equipment of the machine.

From the above we can deduce that:

- the positive and negative chambers are pneumatically independent;
- the chamber opposite to the direction of movement of the piston stroke must be in connection with the atmosphere.

Referring to the diagram below, we observe the situation of the pressure in the chambers of a double acting cylinder during the movements of a stroke.

Figure 6
Phase 1: Piston stopped against the rear head

- Positive chamber: is at atmospheric pressure, which corresponds to a pressure of zero on the manometer.
- Negative chamber: there is the presence of internal pressure; the manometer indicates the value of this pressure.

Now we put compressed air in the positive chamber while we simultaneously exhaust the negative chamber.
Phase 2: Pressurization/exhaust

- Pressurization positive chamber: considering the reduced volume when the piston is in this position, the pressure rises immediately until it reaches point **A**, where it stabilizes towards the value of the supply pressure, the cylinder is yet to begin its movement.
- Negative chamber discharge: the volume of air contained is exhausted into the atmosphere and with the passage of time, this pressure drops gradually. This condition is identical to that which would occur in the phase of emptying a tank.

Phase 3: Movement of the piston
When the value of the thrust Force F_s is greater than the value of the pulling Force F_t and the load being handled ($F_s > F_t$ + load) the piston rod/piston begins its movement. Observe what happens in the chambers:

- Positive Chamber: as the piston rod/piston starts to move and gains speed, a slight pressure drop occurs in this chamber. This situation is present until the end of the stroke.
- Negative Chamber: the curve corresponding to the value where the pressure drop stops at point **B** as the piston rod/piston overcomes the resistance due to the load and starts moving.

The two pressures in the supply and exhaust remain constant until point **C**, which corresponds to the end of the movement.
Phase 4: Pressure stabilisation
Having finished its movement, the cylinder does not consume any more air (point **D**).

- Positive chamber: the initial air pressure is re-established and reaches the value it had in the initial phase (point **A**).
- Negative chamber: the pressure in the dead space and in connection tubes continues to decrease until it reaches atmospheric pressure.

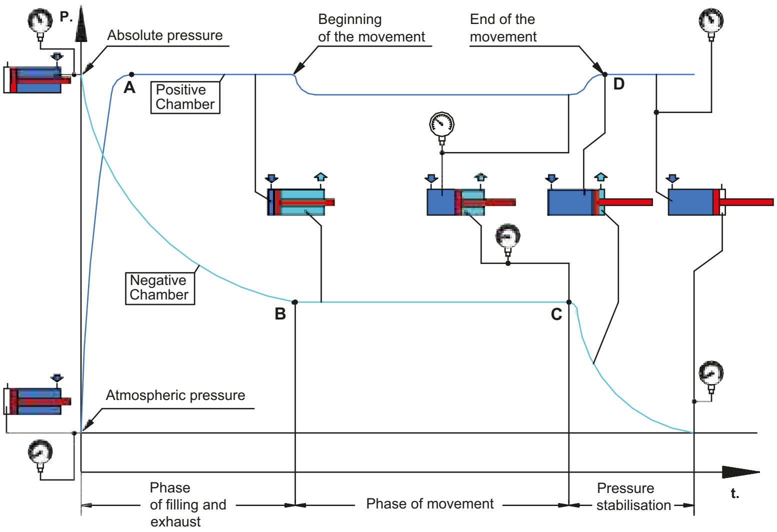


Fig. 6

Developed forces

Figure 7

Double-acting cylinder: a part of the piston surface is occupied by the presence of the piston rod, therefore, the Force *F* developed in each direction is different.

Single-acting cylinder: the Force generated by the working stroke is less than the Force generated by an equivalent dimensioned double-acting cylinder, due to the reaction caused by the return spring.

Variables that determine the value of the Force *F*:

- **Pressure *p***.
- **Piston surface areas S_s and S_t**: there is a difference between the thrust surface “S_s” and the traction surface “S_t”, which is less due to the presence of the piston.
- **Friction resistance µ**: occurs between two moving surfaces in contact, in particular:
  - between the piston rod and the bearing bush in the front end cap;
  - between the piston rod and the wiper seal;
  - between the piston seals and the cylinder barrel.

These resistances affect approximately 10% of the frictional Force, for convenience of calculation, we multiply the value of the frictional Force developed by the cylinder by 0,9, which is considered to be the η yield of the cylinder.

Force developed by a D.A (double acting) cylinder:

thrust movement	$F_S = p * S_S * \eta$
traction movement	$F_T = p * S_T * \eta$

Force of the Single-acting cylinder:
we must consider the presence of the return spring. With the cylinder at rest the spring is pre-loaded. The spring presses on the piston. As the spring is compressed its reaction force increases until it reaches a maximum value at the end of the stroke. (The minimum and maximum values vary depending on the diameter and the stroke of the cylinder). The diagram reports the value of F_m in proportion to the extension of the spring.

thrust movement	$F_S = (p * S_S * \eta) - F_m$
traction movement	F_m

To contain the yield of the spring within tolerable limits and ensure the return of the piston with sufficient certainty, the strokes are limited according to the diameters and the construction type of the cylinder.

Example: cylinder has a diameter **D** = 50 *mm* and a stroke **C** = 50 *mm*, when it is at rest, the spring is fully extended and has a load which is slightly less than 80 *N*, when the cylinder completes its positive stroke the spring is fully compressed and has a Force F_m of about 115 *N*.

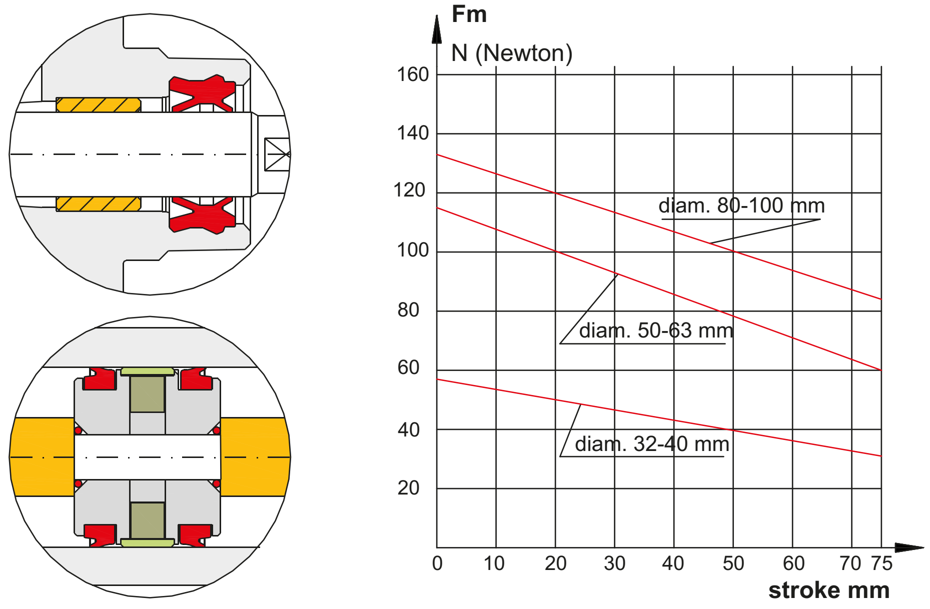


Fig. 7

Constructive characteristics

There are different types of pneumatic cylinders, the most common are:
- with rolled end caps;
- end caps attached to the tube by means of tie rods;
- end caps attached at the profile fixed with screws;
- end caps integrated into the cylinder body and fixed in position with seeger rings;
- threaded end caps.

On the end caps, points for the connection of the attaching elements of the cylinder are located.

Among the various cylinders, there are cylinder ranges that comply with the International Standards as regards the overall dimensions and spacing of the fixing holes, for example:

DIN/ISO 6432 for cylinders with diameters from 8 to 25 *mm*
ISO15552 (which has replaced DIN/ISO 6431 / VDMA 24562) for cylinders with diameters from 32 to 320 *mm*
ISO 21287 for compact cylinders with diameters from 20 to 100 *mm*

The range of applications vary greatly therefore materials and treatments can be customized.

- **Cylinder end caps**: normally they're made of aluminium. In the presence of salt spray (marine environments) or in hostile environments they can be treated, varnished or constructed with other materials.
- **Piston rod**: generally made of stainless steel.
- **Tube/barrel or profile**: usually made of aluminium, which has been anodized. This treatment significantly reduces the effect of scale. Another common material for the tube/barrel is steel (for cylinders of bigger dimensions).
- **Seals**: the shape and the material used are of considerable importance; as well as ensuring the resistance, they must meet the following requirements:
  - chemical resistance to lubricants;
  - low friction and without the tendency towards sticking;
  - resistance to wear and external agents.

  They can be made of different materials e.g. NBR, HNBR, polyurethane, FKM etc..

  Seals are used:
  - on the piston: generally there are two lip seals **A**;
  - on the piston rod: this exerts a dual function of sealing and cleaning/scraping **B**;
  - on the cushioning chambers **C**;
  - on the end caps and the adjustment screws of the cushioning **F** and **D**.

The cylinders may be magnetic, enabling the detection of the position of the piston.
The magnet **E**, which has a well-defined magnetic field, is detected by sensors above the cylinder tube.

Normally the cylinders are:

Figure 8
Single acting (S/A): can be with the return spring either in thrust- or traction mode.
Traction mode: the return spring, guided by the piston rod, keeps the piston rod/piston in negative end position. The hole on the front-end cap serves to maintain the negative chamber in connection with the atmosphere.
Thrust mode: the return spring keeps the piston rod/piston in the positive end position. The hole on the rear end cap serves to maintain the positive chamber in connection with the atmosphere. The spacer **G** allows the correct repositioning of the return spring.

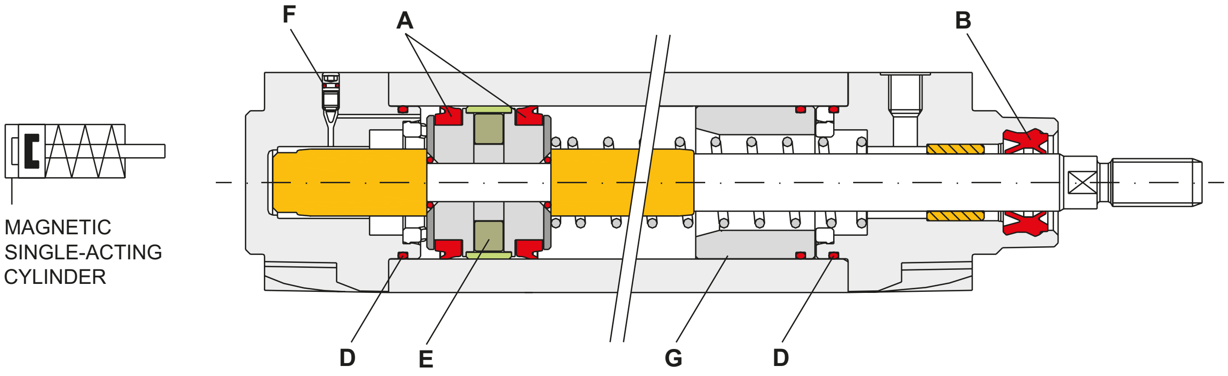


Fig. 8

Figure 9

Double Acting Cylinders (D/A): can be with or without pneumatic adjustable end cushioning at the end of the stroke.

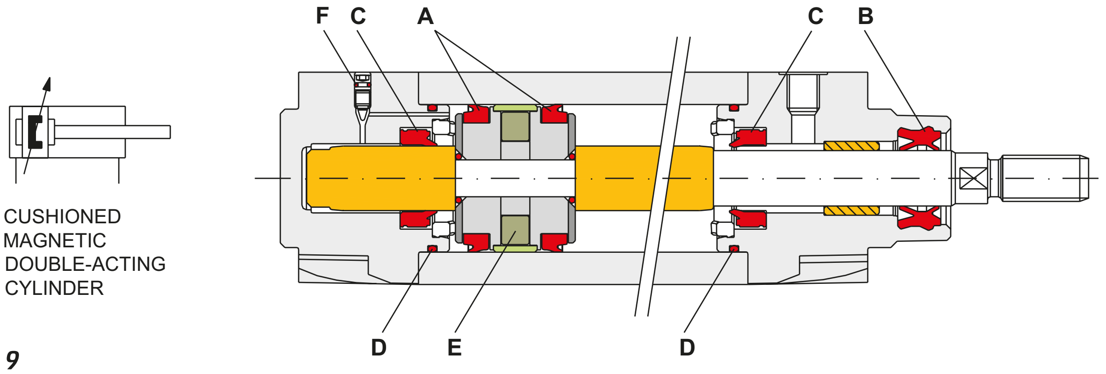


Fig. 9

Sizing of a cylinder according to the applied load

The Force created by a cylinder can be used in two ways:
Statically: when the cylinder completes the stroke "under vacuum" and its Force must intervene onto a fixed obstacle (load), for example the blocking of working pieces, bending operations etc...
The Force *F* required by each of these operations must correspond to the product of the pressure *p*, multiplied by the piston surfaces:

$$F = p * S$$

Dynamically: when the cylinder has to move a load, in this case the evaluation of the Force is made according to the direction of the movement which can be:

Vertically: Force *F* must overcome the resistance of the load;

$$F = m * g$$

Horizontally: Force *F* must overcome the frictional resistance. Its value is equal to the product of the weight of the body *F* multiplied by the friction coefficient "µ" of the support system (sledges, trolleys etc.).

$$F = Fp * \mu$$

At an equal load, horizontal movement requires less Force than vertical movement.

The performance of the pneumatic cylinders may be determined through appropriate adjustments.
The most common are:
Maximum speed: the type of construction, the size of the connection pipes, the capacity of control valves, flow controllers settings combine to determine the speed of the cylinder.
Kinetic energy: is the energy acquired from the load during its movement and must be reduced before the piston reaches the end of the stroke to avoid impact against the cylinder head. In order to reduce the magnitude of this energy, some cylinders are equipped with adjustable cushioning devices, which reduce the speed towards the end of the stroke.

To better understand what has been discussed and to understand the effectiveness of these braking systems, observe the graph illustrating the value of the load to be cushioned on the ***x-axis*** and the piston speed on the ***y-axis***.
This graph was obtained by means of experimental tests using:

- double-acting cylinders;
- load carrying trolley mounted on bearings and mobile on horizontal columns;
- electronic equipment for measuring time;
- test pressure $p = 6$ *bar*.

The kinetic energy is considered to be completely absorbed by the braking phase when, with completely closed cushioning, the piston rod/piston does not reach the cylinder head. This analysis, even if not acceptable by the user for the "bounce" effect of the piston, enables us to determine the parameters of maximum load and speed applicable.
The test was performed by taking the positive stroke of the piston as reference, which is the most penalized because the negative chamber encloses a smaller volume of air, which is the worst condition for damping of the load. With heavy loads appropriately sized external shock absorbers are used.

Figure 10
Pos. A: a cylinder of what dimension is required to damp a weight of 50 *Kg* (500 *N*) at a speed of 300 *mm/sec*?
Starting from the *x* axis (load value) draw a segment at the 50 *kg* that intersects the lines of the maximum load of the cylinders. Starting from the *y* axis (speed) draw a segment that intersects the load. The intersection between the two segments corresponds to the maximum limit of damped energy by a cylinder with a diameter of 32 *mm*.
Pos. B: at what speed can a load of 50 *kg* be displaced using a cylinder with diameter D = 50 *mm*?
The max. speed. is 470 *mm/sec*.
Pos. C: what weight can a cylinder with a diameter *D* = 80 *mm* at a speed of 470 *mm/sec* displace?
The maximum weight is 183 *Kg*.

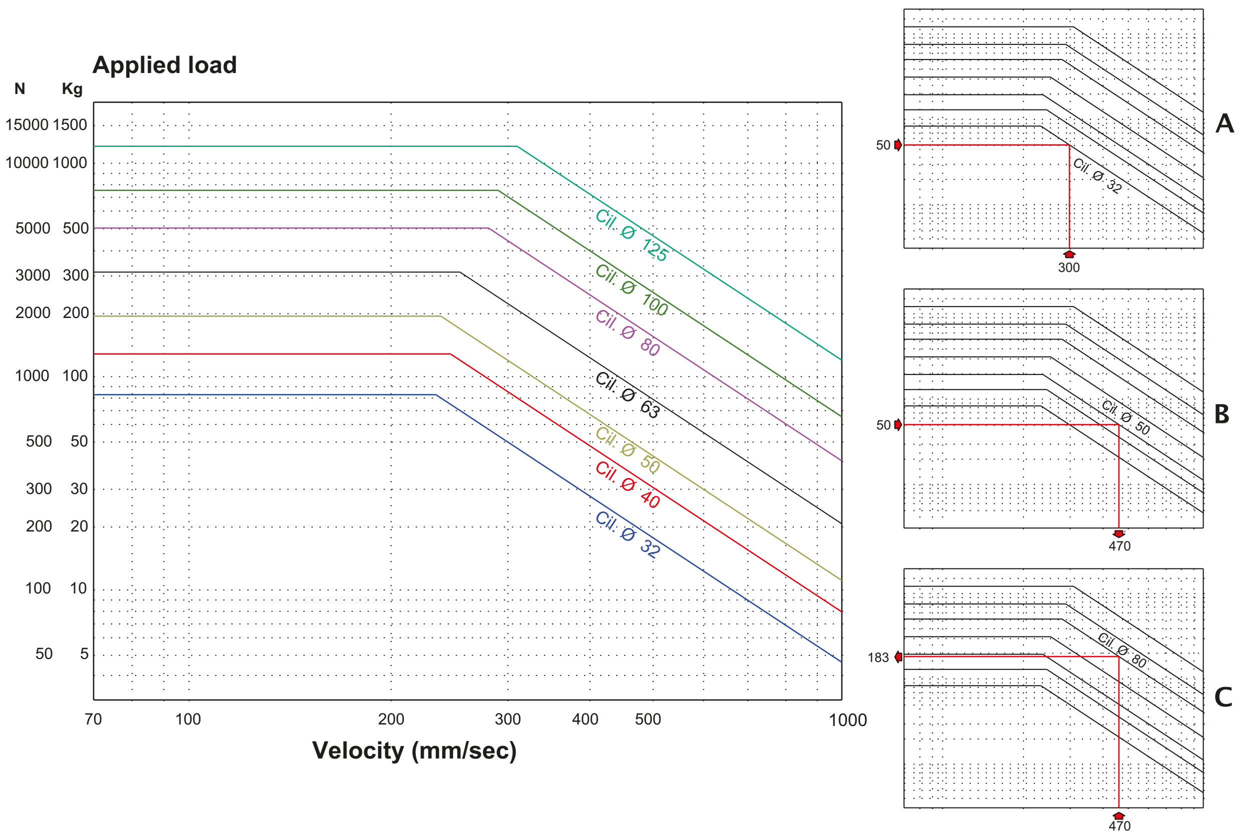


Fig. 10

Cushioning phase of the movement of a double-acting cylinder

To avoid damage to the structure of the cylinder or connected mechanisms, the kinetic energy acquired by the load during movement should be reduced or cancelled before the piston reaches the end position.
Some cylinders are equipped with adjustable cushioning systems (shock absorbers) which, depending on the diameter of the cylinder, act between 15 and 50 *mm* of the final stretch of the stroke. This deceleration is activated automatically and forces the discharged air to pass through an exhaust with a reduced section.
The rise in pressure in the exhaust chamber creates a greater resistance to movement of the piston rod/piston with a consequent reduction of speed.

As illustrated in the previous diagram, there are maximum energy levels that the cushioning systems can absorb, the higher the load the lower the speed, the higher the speed the lower the load.
Using the front head of a cylinder as an example, we verify the operation of the cushioning system.

Figure 11
Pos. 1: Cushioning seal **A** has no function.
The air is free to move as the cushion sleeve **B** is not yet in contact with the inner rim of the seal **A**.
Pos. 2: when the **B** is inserted into the rim of the seal **A**, it will be moved axially in a specific position developing two distinct sealing actions:
static: through the flat surface supporting the cylinder head;
dynamic: when the cushion sleeve is resting on the rim of the seal.
In this situation the quantity of compressed air present between the piston and cylinder head can only exhaust through **C**. The space available for the braking operation is referred to as the “cushioning stroke”.
Pos. 3: the piston has completed its stroke and the reduced pressure from the chamber can be exhausted into the atmosphere.

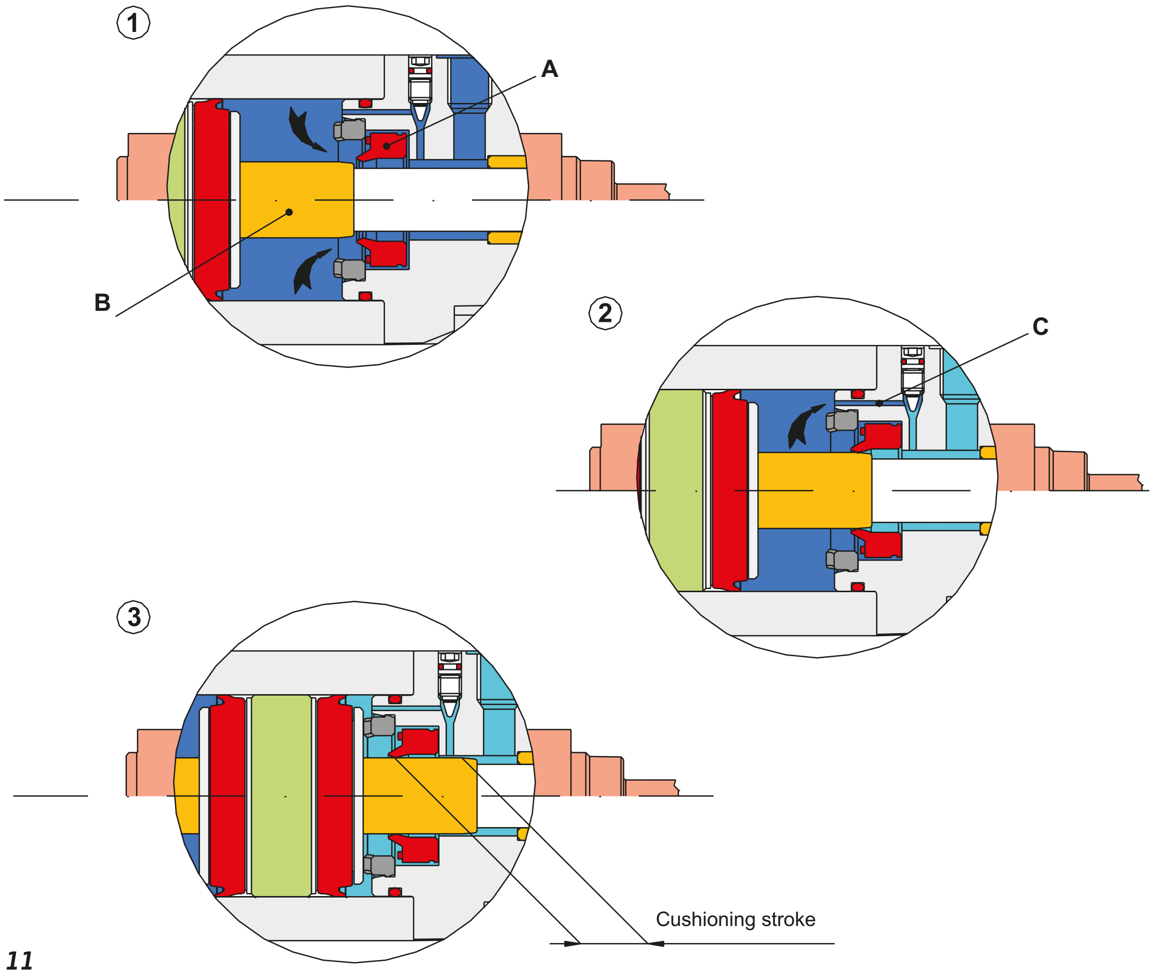


Fig. 11

The above also occurs in the rear head cylinder when the piston returns.

Acceleration phase of a double acting cylinder

We analyze the starting phase of a pneumatic cylinder.

Imagine replacing the cushioning seal with a simple seal with a circular section (commonly called "O-Ring"). When the piston rod/piston reaches the end position the braking effect is similar to that seen in previous chapters, in the starting phase the "dead space" and the volume of the chamber are pressurized, in proportion to the opening of the cushion regulation screw.
This bottleneck delays the commonly called "acceleration" phase i.e. the pressurization of the chamber and the subsequent start of the piston rod/piston which in this area would also have a non-linear movement.

To avoid this condition, seals with a particular profile are used.

Figure 12
Pos. 1: the piston is against the cylinder head, the seal **A** is supported with its flat part against the side of the seat on the cylinder head. On the opposite side, the rim is in contact with the cushioning sleeve.
Pos. 2: with the arrival of the compressed air regardless of the position of the cushion regulation screw, the air flow moves the seal **A** from its previous position towards the piston starting the filling of the volume phase of the chamber **B**.
Pos. 2a: the compressed air passes through the cushion regulation screw and through the spacers on the seal, that detach it from the supporting surface of the piston. In this way the filling takes place more quickly.
Pos. 3: in the chamber **B** of the cylinder we have the supplying pressure. The piston begins its movement only when the generated thrust force overcomes the resistant force.
Pos. 4: the piston rod/piston is moving, and with the exit of the cushion sleeve from the seal we have the maximum flow of compressed air.

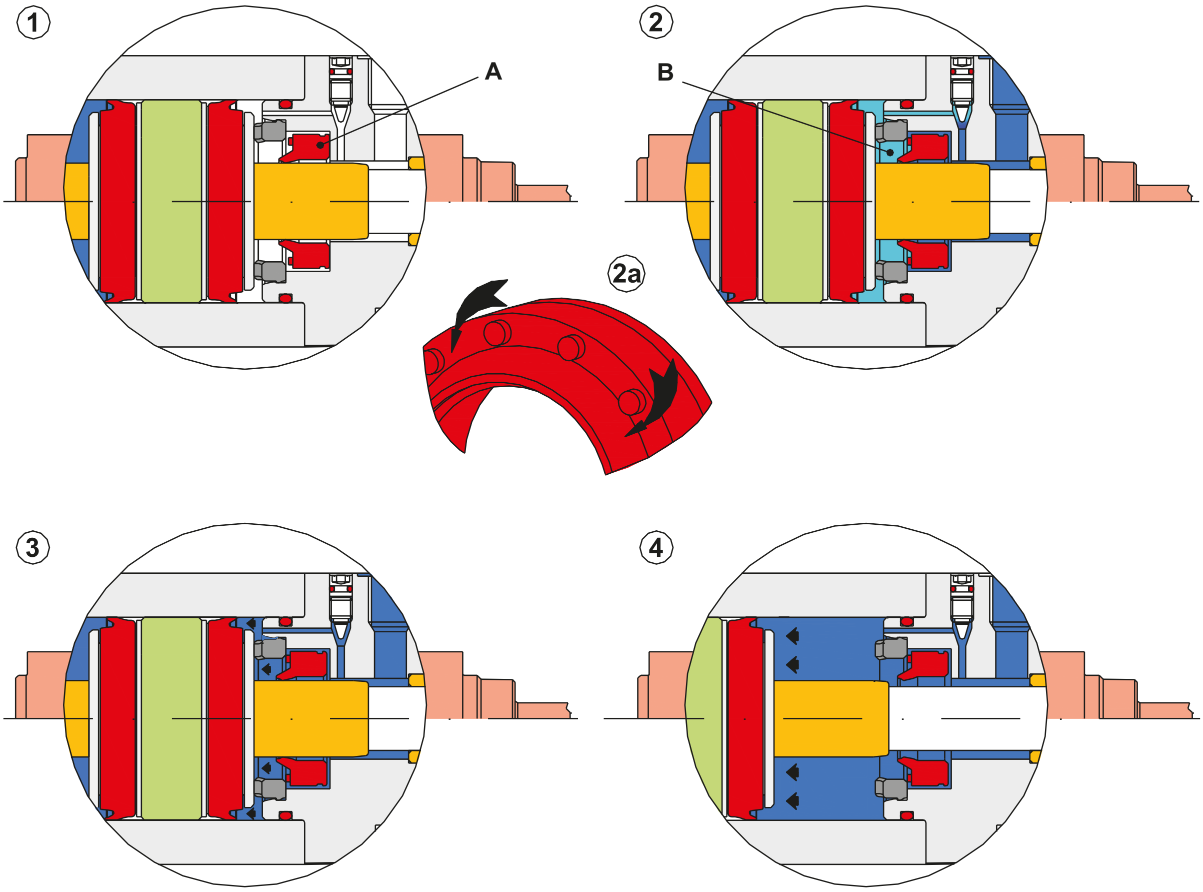


Fig. 12

Cylinder brackets

The cylinder is capable of transforming the energy of the compressed air into mechanical (kinetic) energy.

It is comprised of a static part called the "body" with the dynamic part i.e. the piston connected to the rod.
To enable the driving Force on the axis of the rod to be utilized, the body of the cylinder must be fixed to a structure in an appropriate way.
The elements fixing the body to the structure are defined "brackets" and may be **rigid** or **oscillating**. It is important that the cylinder brackets minimize the radial loads that can be applied to the cylinder.

Examples of rigid cylinder brackets:

Figure 13
Pos. A: **Direct mounting** end caps are fixed directly to the equipment plate.
Pos. B: **Flange**. This accessory allows perfect centering on the end caps. We do not recommend the use of the flange on the rear head except in the case of short stroke cylinders or for installation in a vertical position. The weight of the cylinder and of the piston rod, when outside, would weigh on the flange creating increasing flexion as the length of the stroke increases.
Pos. C: **Foot mounting**. Fixed directly to the two end caps, they allow the mounting of the cylinder on any surface, provided it is parallel to the axis of the cylinder.

Examples of oscillating cylinder brackets:

Figure 13
Pos. D and **F**: **Rear trunnion**. This accessory can be supplied with the male trunnion. Their combination allows both the oscillation and the fixing on the structure of the machine.
Pos. E: **Front trunnion**. Owing to the presence of the rod, this is the only bracket possible for the front end cap. The support of the trunnion must be positioned on the structure of the machine.
Pos. G: **Centre trunnion**. This is a type of oscillating cylinder bracket offering the possibility of being fixed on the tube or on the cylinder profile at any point between two end caps.

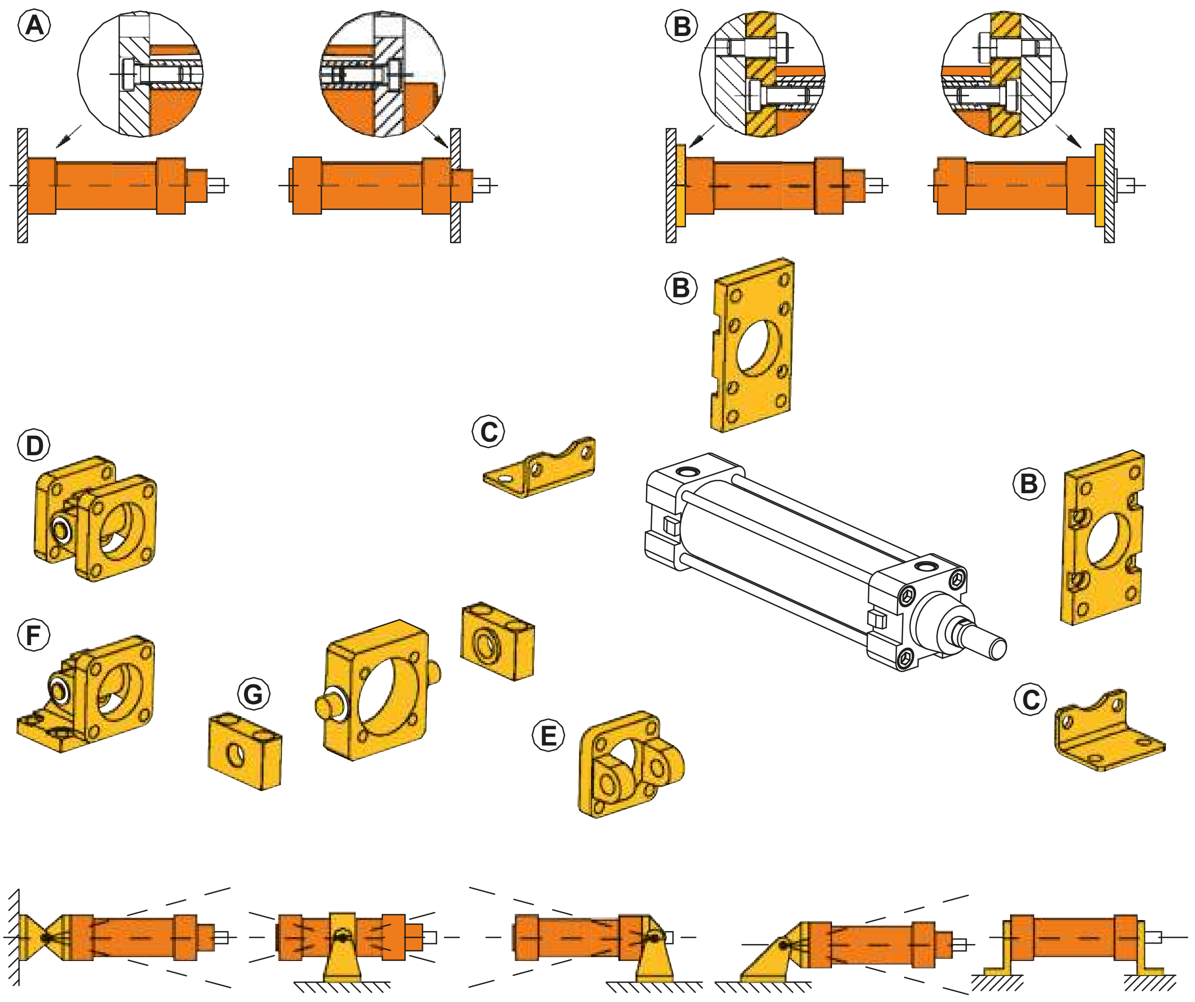


Fig. 13

Piston rod mountings

The connection of the cylinder body and the connection of the piston rod when mounted on the object to be driven must be done in such way that any misalignment between the axis of the piston rod, body and the driven object is eliminated. Before putting an installation into operation, it is advisable to check the alignment of the load with the piston rod from its retracted to extended position. An incorrect alignment will generate a radial Force on the piston rod which eventually will cause deformation of the guide bush which consequently leads to premature wear of the tightening seals on the piston rod and piston.

Figure 14
Pos. 1: the object to be moved is not bound to any guides and the rod can be directly secured to the moving object. This fixture is defined as **direct**.
Pos. 2: fastening by means of a **rod fork**. Provides liberty of movement in one axis, hence does not provoke any radial Force due to the motion of the attached object in that axis.
Pos. 2a: the moving load travels along an axis parallel to the cylinder centre line with a lateral deviation in the horizontal plane of angle β. In this situation the rod exerts a radial load on the guide bush, by inserting a rod fork you compensate for that angle and substantially reduce the radial load.
Pos. 2b: the load movesupwards of angle β and the piston rod is forced to work on the upper part of bushing: also in this case the fork, with a different orientation, is able to compensate the misalignment.
Pos. 3: secured with **swivel ball joint**.
Pos. 4: fastening by means of a **piston rod socket joint**.

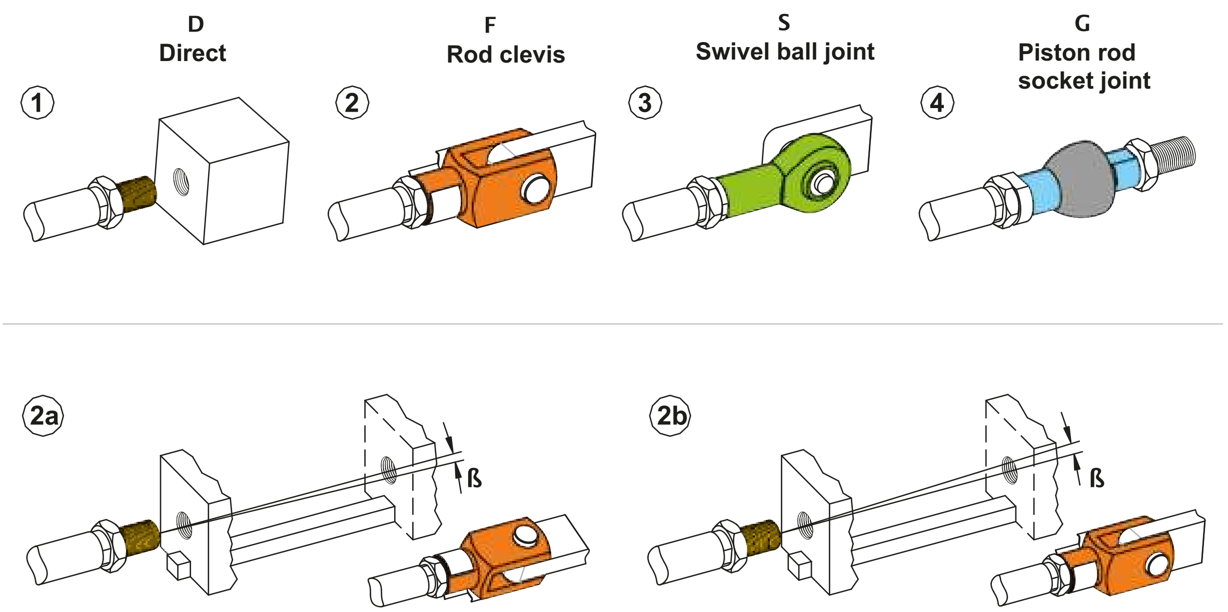


Fig. 14

Figure 15
Pos. 5: if the misalignment occurs in the two planes, the bush will be subject to wear in these two planes. By inserting a swivel ball joint **S** or a piston rod socket joint **G** it is possible to compensate for that misalignment.
Pos. 6: the angular movement is always occurring on the same plane. With this assumption, and with the evident need to support the cylinder with a bracket that allows the cylinder to oscillate, the piston rod can be connected to the lever with a rod fork **F**. If there's any doubt about the movement remaining on the same plane, a swivel ball joint **S** should be used instead. With this solution it is advisable to check the radial load generated by the weight of the cylinder. When the rod is in external position this load is acting on the bronze bushing, provoking damage. In particular, with long strokes it is preferable to use a cylinder mounting with a center trunnion.

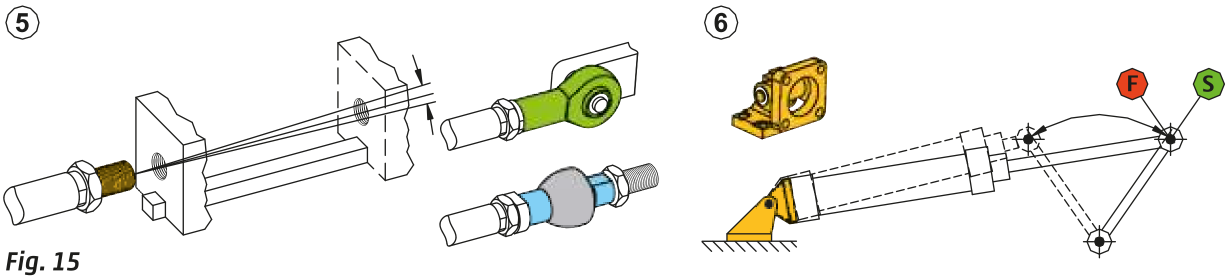


Fig. 15

Rod stress with a compression load

While progressively pressing the ends of a wooden match held between thumb and index finger, we notice that it bends until it reaches breaking point; repeating the same procedure with one of the broken parts, if we are to achieve the same result, we need to apply a much greater force.

Figure 16
Pos. 1: assume that, the match is represented by a rod of length X, and that under the action of a Force F_1 the rod bends.
Pos. 2: if one end of the rod is constrained, in order to obtain flexing, a greater Force is necessary than in the previous case $F_2 > F_1$. The rod undergoes a bigger curvature and only in the non-guided part.
Pos. 3: with both ends of the rod constrained, the Force F_3 needed to flex the piece is even greater $F_3 > F_2$. The central part of the rod undergoes a curvature.

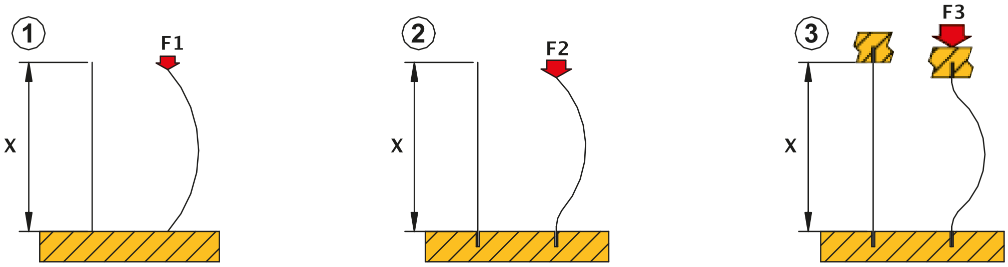


Fig. 16

With this example we want to highlight the fact that a piston rod, when compressed along the axis by a Force, tends to flex with the possibility of breakage. This stress composed of "pressure-flex" is defined as "compression load" and occurs when the length of a rod exceeds its diameter by 10 times.
The cylinders, according to regulations, have standards regarding these combinations between the dimension of the rod and its diameter. The choice of the cylinder, made according to the thrust Force F_S to be developed and the dimension of the piston rod, is a consequence of this ratio.

Examples of installation:

Figure 17
Pos. A: the cylinder is rigidly fixed to the structure; the piston rod is fixed to an object moving on a surface. We introduce a mechanical stop to the load so that the cylinder does not reach the end of the stroke. The Force from the piston and the retaining load compresses the piston rod. The value of this Force is:

$$F = p * S$$

Figure 17
Pos. B/1-B/2-B/3: the piston rod end is hinged and the working end is guided, the cylinder is fixed in different ways and in different positions.
Pos. C: the rod attachment is identical to Pos. B. the cylinder body is rigidly fixed to the structure.
Pos. D: the cylinder body is rigidly fixed to the structure; the rod is inserted in the work-piece, which is guided.

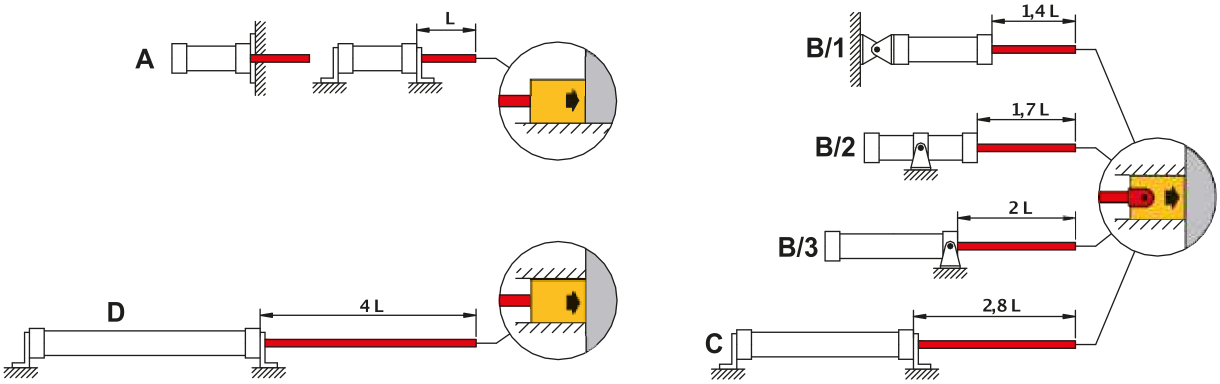


Fig. 17

Verification of the maximum load:

Figure 18
Diagram A: using the value of the Force F_S *[N]* proportionate to the pressure *p [bar]*, the diagram allows you to choose the diameter of the cylinder along with the rod as indicated in parentheses.
Diagram B: based on the Force F_S *[kg]* and the length of the rod *L [mm]*, the diagram shows the maximum possible length for the worst-case connection, as indicated in Pos. A.

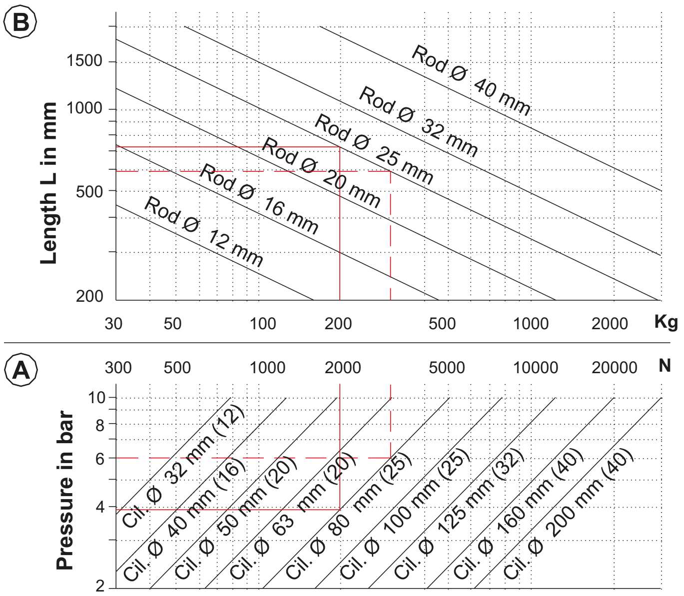


Fig. 18

Example 1: to find a cylinder that can exert a thrust Force F_S = 2000 *N*, with a stroke *L* = 1400 *mm* and a pressure *p* = 6 *bar*.

Figure 18
Diagram A
Starting from the value F_S = 2000 *N* various lines cross, the one representing a cylinder *D* = 80 *mm* with a 25 *mm* rod permits operation with the required pressure. Since the stroke of 1400 *mm* is greater than **10 times the diameter of the rod** (25 *mm* in the example given), a compression load verification is required.
Diagram B
The selected cylinder, with *p* = 6 *bar*, develops a Force F_S = 3000 *N* (approx). To have a value F_S = 2000 *N* it is necessary to limit the pressure to 4 *bar*.
From the value of 2000 *N*, we follow the vertical line until it reaches the "rod Ø 25 *mm*" line and this gives a reading of maximum length *L* = 700 *mm* (approx.).

Possible installation types:

Figure 17
Pos. B/1: is not possible, this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 700\ mm \ast 1{,}4 = \mathbf{980\ mm}$$

Pos. B/2: is not possible, this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 700\ mm \ast 1{,}7 = \mathbf{1190\ mm}$$

Pos. B/3: is at the limit so there is no margin of safety. This installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 700\ mm \ast 2 = \mathbf{1400\ mm}$$

Pos. C: this installation type is the only possible variant and offers a good margin of safety

$$L_{max} = 700\ mm \ast 2{,}8 = \mathbf{1960\ mm}$$

Example 2: to find compression load and installation type for a cylinder with diameter $D = 50\ mm$, stroke $L = 700\ mm$ and a pressure $p = 6\ bar$.

Figure 18
Diagram A
In correspondence with the value $p = 6\ bar$, we follow a horizontal segment until the inclined "diameter $D = 50\ mm$ (20 *mm* rod)" line, from the x axis we note that the value of the compression load is of

$$F_s > 1000\ N$$

Diagram B
From the above junction, draw a vertical segment that meets the "rod Ø 20 *mm*" to give a value of $L = 600\ mm$ (approx.)

Possible installation types:

Figure 17
Pos. B/1: this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 600\ mm * 1{,}4 = \mathbf{840\ mm}$$

Pos. B/2: this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 600\ mm * 1{,}7 = \mathbf{1020\ mm}$$

Pos. B/3: this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 600\ mm * 2 = \mathbf{1200\ mm}$$

Pos. C: this installation type enables the cylinder to develop a maximum stroke length

$$L_{max} = 600\ mm * 2{,}8 = \mathbf{1680\ mm}$$

All connections are possible.

Devices to modify the cylinder performance

The lever

The strength of a cylinder can be modified with mechanical **levers**.

Figure 19
Pos. 1: the lever is a rigid rod with a pivot at the point called the **fulcrum** *(fc)*. At the extreme end of this rod, a Force F is applied. The perpendicular distance from the line of action of the Force to the axis of rotation (pivot), is referred to as the **arm** *(b)*.
The product of the Force multiplied by the arm generates a component defined as **Moment of a force**.

$$m = F * b$$

When lifting a load you have two Forces: the power P (generated by the cylinder) and resistance R (the body's weight to be lifted). From the product of each Force multiplied by the respective arms you arrive at the "moment of power" and the "moment of resistance".
The lever is in equilibrium when the two moments are equal, i.e. when:

$$bp * P = br * R$$

Example: through a lever and a cylinder we can lift a load and bring it into a position of equilibrium. It is possible to achieve balance with three different positions of the cylinder relative to the fulcrum and resistance, as shown below.

Figure 19
Pos. 2: the fulcrum *fc* is located between the power *P* and the resistance *R* (first type of lever).

Value of the load $R = 12\ Kg\ (120\ N)$

Lever length $PR = 1100\ mm$

Distance of the fulcrum from the point of application of resistance $fcR = 660\ mm$

Calculation of the distance of the fulcrum from the point of application of power *fcP*

$$fcP = PR - fcR = 1100 - 660 = \mathbf{440\ mm}$$

its state of equilibrium RR_1 is possible with a displacement of 550 *mm*.

Calculation of the cylinder stroke, using the similarity of the triangles $fcPP_1$ and $fcRR_1$:

$$fcP : fcR = PP_1 : RR_1 \qquad PP_1 = \frac{fcP_1 * RR_1}{fcR} \qquad PP_1 = \frac{440\ [mm] * 550\ [m]}{660\ [mm]} = \mathbf{366\ mm}$$

Using the **Pythagorean** theorem, we calculate the length of the arms b_r and b_p

$$b_p = \sqrt{(fcP)^2 - (1/2\ PP_1)^2} \qquad b_p = \sqrt{(440)^2 - (1/2 * 366)^2} \cong \mathbf{400\ mm}$$

$$b_r = \sqrt{(fcR)^2 - (1/2\ RR_1)^2} \qquad b_r = \sqrt{(660)^2 - (1/2 * 550)^2} \cong \mathbf{600\ mm}$$

For the equilibrium of moments we know that:

$$b_p * F = b_r * R \qquad F = \frac{b_r * R}{b_p} \qquad F = \frac{600\ [mm] * 12\ [N]}{400\ [mm]} = \mathbf{180\ N}$$

The Force *F* required to bring balance into the system is 180 *N*.

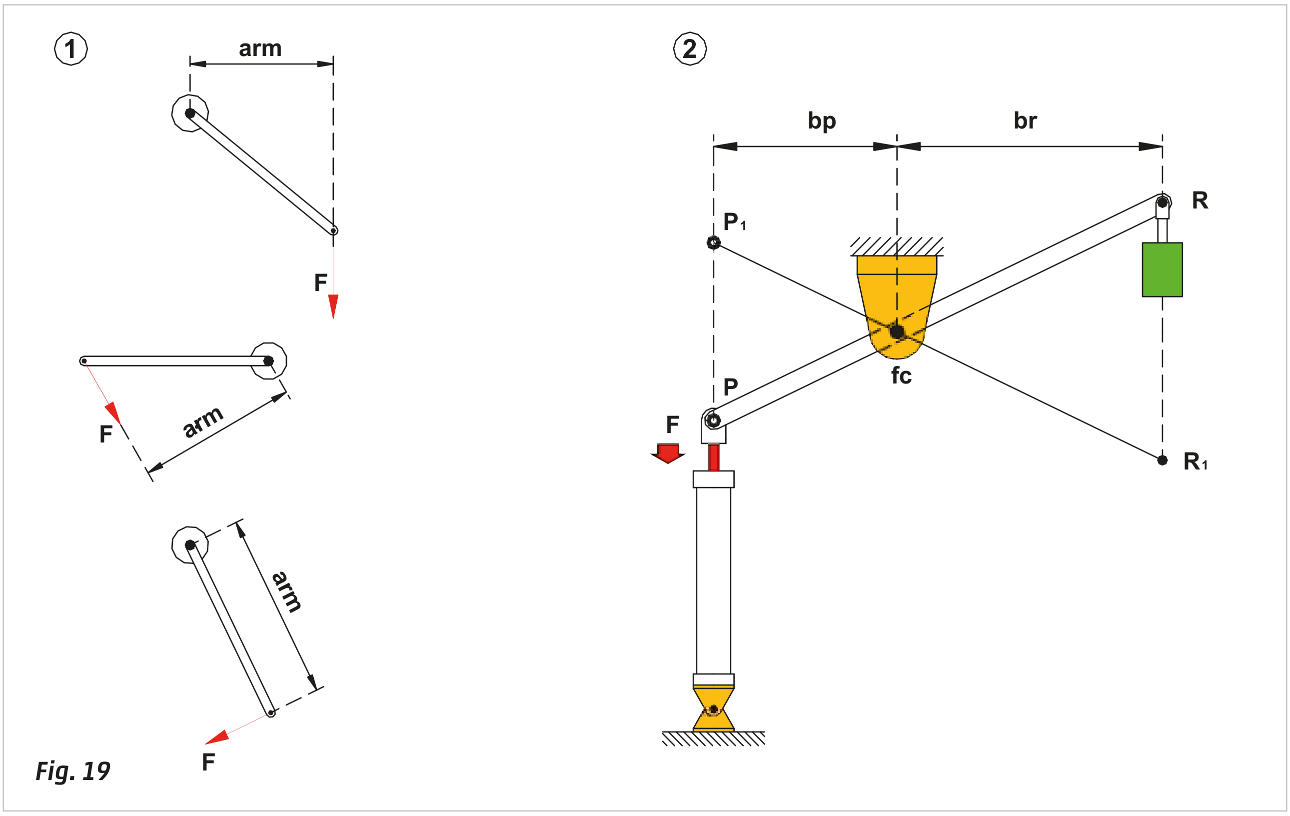


Fig. 19

Figure 20
Pos. 3: the resistance *R* is located between the fulcrum *fc* and the power *P* (second type of lever).

Value of the load R = 12 *Kg* (120 *N*)

The arm b_p = 1000 *mm*

Distance of the fulcrum from the point of application of resistance fcR = 660 *mm*

Distance of the fulcrum from the point of application of power fcP = 1100 *mm*

State of equilibrium RR_1, is possible with a displacement of 550 *mm*.

Calculation of the cylinder stroke, using the similarity of the triangles $fcPP_1$ and $fcRR_1$:

$$fcP : fcR = PP_1 : RR_1 \qquad PP_1 = \frac{fcP_1 * RR_1}{fcR} \qquad PP_1 = \frac{1100\,[mm] * 550\,[m]}{660\,[mm]} = \mathbf{916\ mm}$$

Calculation of the resisting arm

$$b_r = \sqrt{(fcR)^2 - (½\,RR_1)^2} \qquad b_r = \sqrt{(660)^2 - (½ * 550)^2} \cong \mathbf{600\ mm}$$

For the equilibrium of moments we know that:

$$b_p * F = b_r * R \qquad F = \frac{b_r * R}{b_p} \qquad F = \frac{600\,[mm] * 12\,[N]}{1000\,[mm]} = \mathbf{72\ N}$$

The Force *F* needed to place the system in equilibrium is 72 *N*.

Figure 20
Pos. 4: the power *P* is located between the fulcrum *fc* and the resistance *R* (lever of the third type).

Value of the load R = 12 *Kg* (120 *N*)

The arm b_p = 400 *mm*

The arm fcR = 1000 *mm*

State of equilibrium should be possible with a displacement of 550 *mm* (RR_1)

Calculation of the cylinder stroke, using the similarity of the triangles and $fcPP_1$ and $fcRR_1$:

$$b_p : b_r = PP_1 : RR_1 \qquad PP_1 = \frac{b_p * RR_1}{b_r} \qquad PP_1 = \frac{400\,[mm] * 550\,[m]}{1000\,[mm]} = \mathbf{220\ mm}$$

Calculating the cylinder force, for the equilibrium of moments we have

$$F * b_p = b_r * R \qquad F = \frac{b_r * R}{b_p} \qquad F = \frac{1000\,[mm] * 12\,[Kg]}{400\,[mm]} = 30\ Kg \cong \mathbf{300\ N}$$

The Force *F* required to equilibrate the system is 300 *N*.

Ideally, for a correct cylinder sizing, the cylinder should create a force that is at least 25% more than the value of the load.

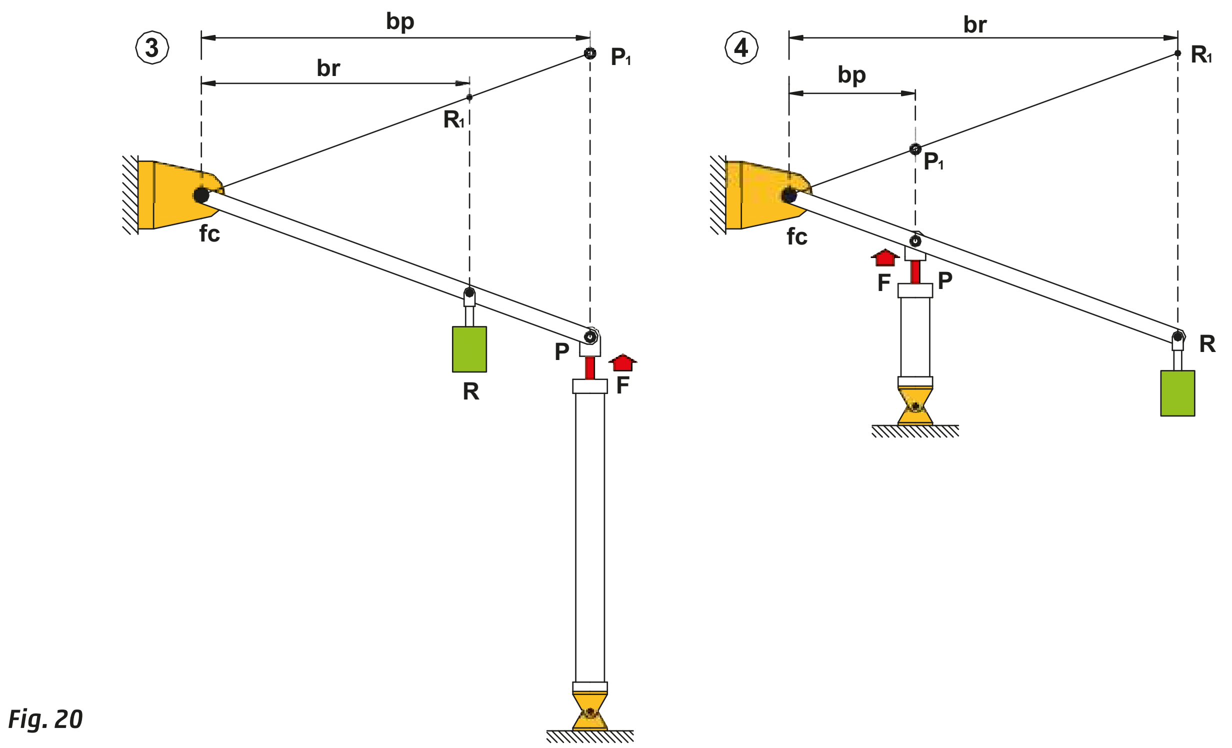


Fig. 20

Devices to modify the cylinder performance

The crank handle

The crank is a device that allows for the transformation of the rectilinear movement of a cylinder into a reciprocating angular movement. It consists of a rigid rod with one end pivoted on a fork rod which receives the movement from the cylinder, the other end is rigidly coupled with a shaft which transmits the rotational movement

An example of the crank is the bicycle pedal.

Figure 21
Pos. 1: using a lever, the cylinder must perform a rotation to the pin in position **A**.
The torque acting on the pin is equivalent to:

$$M_t = F_S * b_{min}$$

F_S is the force applied by the cylinder, b_{min} is the length of the arm in this position.
The torque developed by the cylinder is directly proportional to the length of the arm: the smaller the length of the arm, the lower the torque developed.

Figure 21
Pos. 2: the lever has reached the position in which the arm length is max. The torque is at the max.

$$M_t = F_S * b_{max}$$

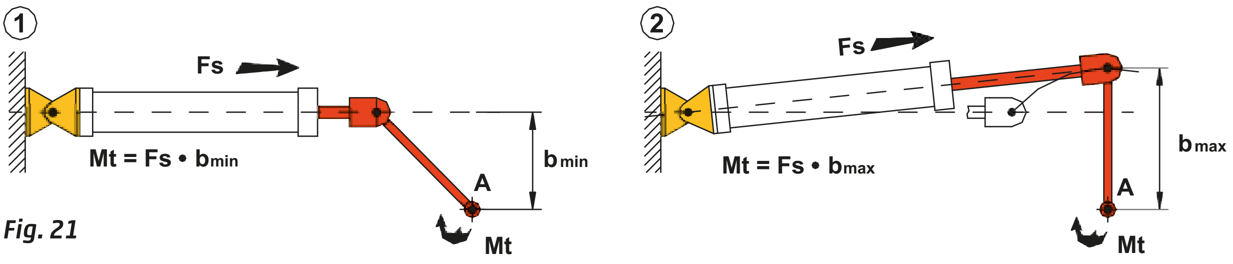


Fig. 21

Figure 22
Pos. 3: the arm is reduced and consequently the torque is smaller.
To determine the stroke of the cylinder relative to β we need:

the angle β

length of the crank *r*

value of *h*

With this data we obtain the length of the arm

$$b = r * \sin\left(\frac{180° - \beta}{2}\right)$$

From which the stroke *C*:

$$C = 2\sqrt{r^2 - b^2}$$

Example of the calculation of the stroke *C* of a cylinder

Length of the crank $r = 500\ mm$

Angle $\beta = 90°$

Calculating the length of the arm *b*:

$$b = r * \sin\left(\frac{180° - \beta}{2}\right) \qquad b = 500\ [mm] * \sin\left(\frac{180° - 90°}{2}\right) \qquad b = 500\ [mm] * \sin 45° \qquad b = \mathbf{353\ mm}$$

Calculation of the stroke *C*

$$C = 2\sqrt{r^2 - b^2} \qquad C = 2\sqrt{500^2\ [mm] - 353^2\ [mm]} \qquad C = 2\sqrt{250000 - 124609} \qquad C = \mathbf{708\ mm}$$

Figure 22
Pos. 4: impact of the variation of the angle on the stroke and the cylinder diameter assuming the torque is 100 *Nm*.

Length of the crank $r = 450\ mm$

The angle $\alpha = 90°$

Calculate the length of the arm b_1:

$$b_1 = r * \sin\left(\frac{180° - \beta}{2}\right) \qquad b_1 = 450\ [mm] * \sin\left(\frac{180° - 90°}{2}\right) \qquad b_1 = 450\ [mm] * \sin 45° \qquad b_1 = \mathbf{318\ mm}$$

In this position, in order to have 100 *Nm* of torque we will need a cylinder that develops a Force:

$$F_s = \frac{M_t}{b_1} \qquad F_s = \frac{100\ [Nm]}{0{,}318\ [m]} \qquad F_s = \mathbf{314\ N}$$

the necessary stroke length of the cylinder will be:

$$C = 2\sqrt{r^2 - b^2} \qquad C = 2\sqrt{450^2\ [mm] - 318^2\ [mm]} \qquad C = 2\sqrt{202500 - 101124} \qquad C = \mathbf{636\ mm}$$

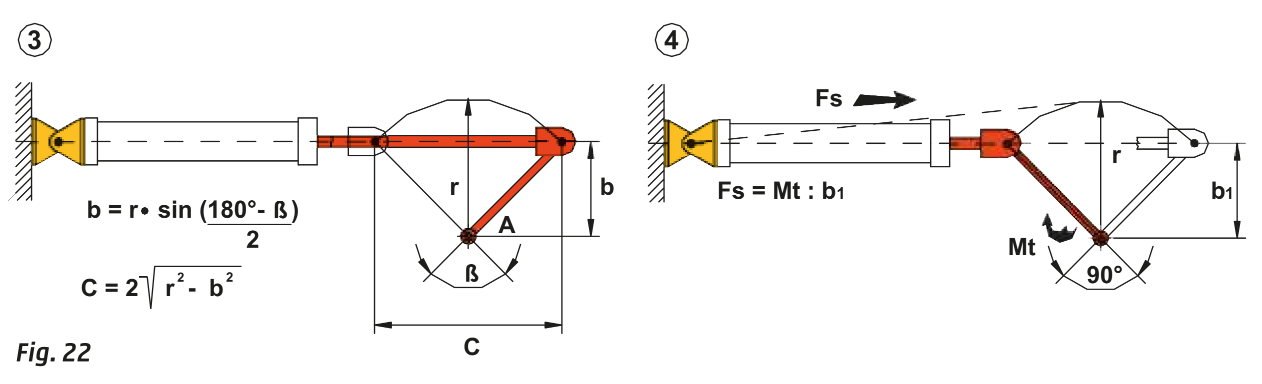


Fig. 22

Figure 23
Pos. 5: impact of the variation of the angle on the stroke and the cylinder diameter assuming the torque is of 100 *Nm*.

Length of the crank $r = 450\ mm$

Angle $\alpha = 120°$

Calculate the length of the arm b_2:

$$b_2 = r \ast sin\left(\frac{180° - \beta}{2}\right) \qquad b_2 = 450\ [mm] \ast sin\left(\frac{180° - 120°}{2}\right) \qquad b_2 = 450\ [mm] \ast sin\ 30° \qquad b_2 = \mathbf{225\ mm}$$

In this position, in order to have 100 *Nm* of torque we need a cylinder that develops a Force:

$$F_s = \frac{M_t}{b_2} \qquad F_s = \frac{100\ [Nm]}{0{,}225\ [m]} \qquad F_s = \mathbf{444\ N}$$

the necessary stroke length for the cylinder will be:

$$C = 2\sqrt{r^2 - b^2} \qquad C = 2\sqrt{450^2\ [mm] - 225^2\ [mm]} \qquad C = 2\sqrt{202500 - 50625} \qquad C = \mathbf{779\ mm}$$

Figure 23
Pos. 6: impact of the variation of the angle on the stroke and the cylinder diameter assuming a torque of 100 *Nm*.

Length of the crank $r = 450\ mm$

The angle $\alpha = 150°$

Calculate the length of the arm b_3:

$$b_3 = r \ast sin\left(\frac{180° - \beta}{2}\right) \qquad b_3 = 450\ [mm] \ast sin\left(\frac{180° - 150°}{2}\right) \qquad b_3 = 450\ [mm] \ast sin\ 15° \qquad b_3 = \mathbf{116\ mm}$$

In this position, in order to have 100 *Nm* of torque we need a cylinder that develops a Force:

$$F_s = \frac{M_t}{b_3} \qquad F_s = \frac{100\ [Nm]}{0{,}116\ [m]} \qquad F_s = \mathbf{862\ N}$$

the necessary stroke length of the cylinder will be:

$$C = 2\sqrt{r^2 - b^2} \qquad C = 2\sqrt{450^2\ [mm] - 116^2\ [mm]} \qquad C = 2\sqrt{202500 - 13456} \qquad C = \mathbf{869\ mm}$$

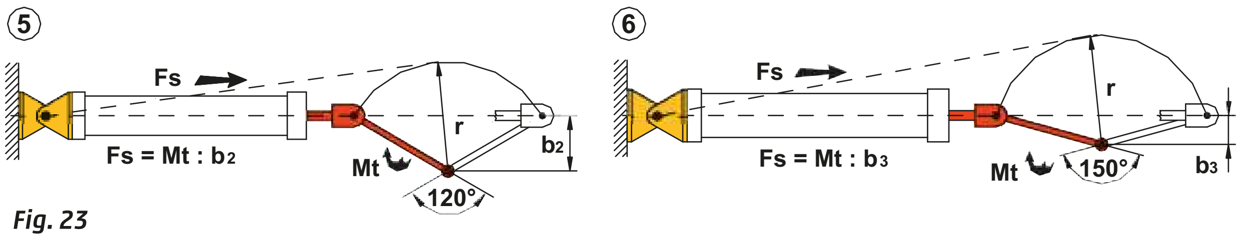


Fig. 23

From the previous examples, it appears that for the same length of crank and torque to be overcome, with the increase of the angle of rotation the stroke length and the cylinder bore must also increase.
With a further increase of the angle, which is equivalent to further reducing the smaller arm, the axis of rotation of the crank approaches the line of action of the cylinder Force impeding its movement, hence the need to use the crank only for angles of rotation of less than 150°.
At higher angles, the use of rotating cylinders, in which the transformation of the movement takes place inside the cylinder, are needed (as we will observe in following arguments).

Geared mechanisms

Geared mechanisms consist of the interaction of at least two gears in such a way that the motion of one gear results in the movement of the other. The resulting motion between these components can be:

- from circular to circular;
- from circular to linear;
- from linear to circular.

Since the movement of a cylinder is linear, the motion that we are interested in is from linear to circular. The set of gears capable of transforming the linear motion into (rotary motion) circular is normally defined "rack and pinion" (the pinion gear is a wheel of small diameter, while the rack is considered a wheel of infinite diameter, so that it forms a straight rod).

Figure 24
In this example, linear motion is converted into circular motion to then be transformed again into a linear motion. The pinion **F** connected to the rod rotates on the pin, the fixed rack located above, forces the pinion to rotate counter clockwise transferring motion to the lower mobile rack.
This rotation is added to the stroke of the cylinder stroke **C**, and the sum of these two motions, are transmitted to the lower rack resulting in a stroke twice the stroke **C** of the cylinder.

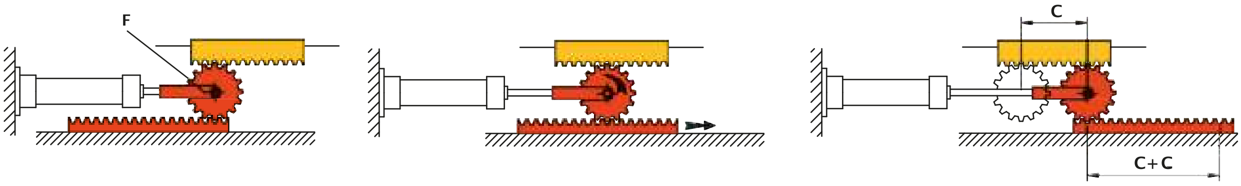


Fig. 24

Figure 25
Pos. A: the motion given to the rack through the cylinder is transformed from straight into circular. By varying the number of teeth of the rack/pinion group, it is possible to have the pinion execute pre-determined rotation angles, or a different number of revolutions.

Example: Number of teeth on the rack $Zc = 40$

Number of teeth on the pinion $Zp = 20$; $Zp = 40$; $Zp = 50$; $Zp = 80$

With the following formula we calculate the number of rotations of the pinion

$$N_{.rot.pign.} = \frac{Zc}{Zp} \qquad N_{.rot.pign.} = \frac{40}{20} = \mathbf{2} \qquad \frac{40}{40} = \mathbf{1} \qquad \frac{40}{50} = \mathbf{0{,}8} \qquad \frac{40}{80} = \mathbf{0{,}5}$$

And the corresponding value in degrees

$$360 * 2 = \mathbf{720°} \qquad 360 * 1 = \mathbf{360°} \qquad 360 * 0{,}8 = \mathbf{288°} \qquad 360 * 0{,}5 = \mathbf{180°}$$

Pos. B: mechanism used for the displacement of materials on planes of different height. The movement takes place "step by step" by means of a toothed wheel **1**, which engages a pawl **2** hinged on the crank **3**, which is controlled by a cylinder.

For the entire length of the positive stroke of the cylinder, the pawl remains engaged always on the same tooth (Pos. a, b) putting the toothed wheel into rotation. The stroke of the cylinder corresponds to the necessary "step". With the return of the cylinder, the pawl disengages (Pos. c) positioning itself in front of another tooth, once it reaches the negative end position, the cycle is repeated.

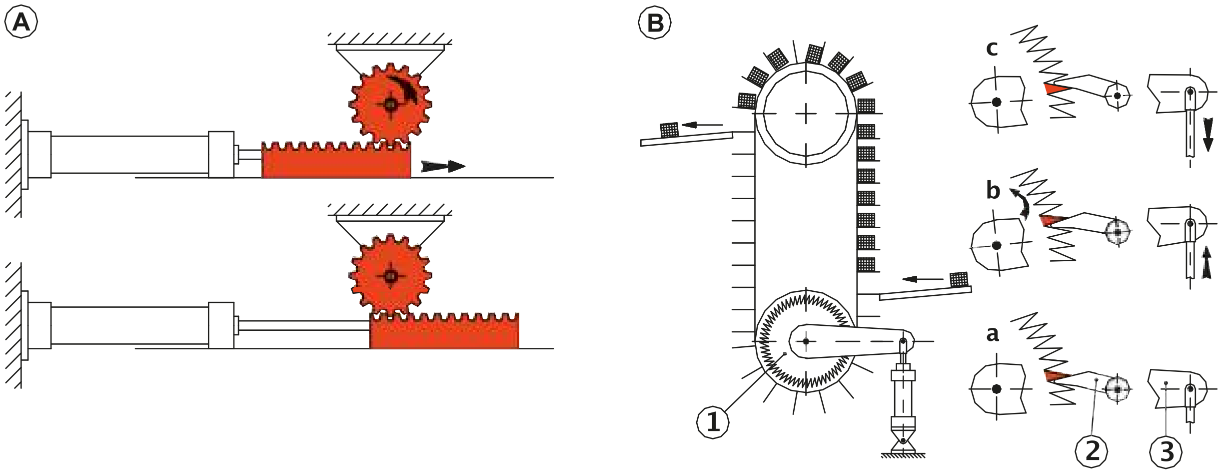


Fig. 25

The wedge

As noted in previous sections, the function of the cylinder is not restricted to that of moving a object, it is able to perform numerous tasks. In this section, we analyze its use as blocking device. It is sometimes necessary to include devices, which prevent movement in the event of air pressure failure.

The **wedge** is a simple and economic device, which is suitable for such an application. It consists of a prism, the section of which can be:

- a right angled triangle, if used on a simple inclined plane;
- an isosceles triangle, if used on a double inclined plane.

Figure 26

The simple wedge

This device allows a large Force F_v to be obtained, by applying a smaller Force value F_s.

By altering the ratio between the height and length of the base, the value of F_v changes drastically.

Examples:

Suppose we require a Force $F_v = 1000\ N$ with a wedge of height $a = 10\ mm$, and with a base $b = 100\ mm$. The value of the thrust Force to be applied F_s is given by:

$$F_s = F_v * \frac{a}{b} \qquad 1000\,[N] * \frac{10\,[mm]}{100\,[mm]} = 100\ N \qquad F_s = \mathbf{100\ N}$$

By halving the height i.e. value $a = 5\ mm$, the thrust Force F_s becomes:

$$F_s = F_v * \frac{a}{b} \qquad 1000\,[N] * \frac{5\,[mm]}{100\,[mm]} = 50\ N \qquad F_s = \mathbf{50\ N}$$

To obtain a $F_s = 50\ N$ maintaining the height $a = 10\ mm$ we will change the base b to a value of:

$$F_s = F_v * \frac{a}{b} \qquad b = \frac{F_v * a}{F_s} \qquad \frac{1000\,[N] * 10\,[mm]}{50\,[N]} = 200\ mm \qquad b = \mathbf{200\ mm}$$

To halve the value of F_s it is therefore necessary to halve the value of a or double the value of b.

The wedge, under the effect of the thrust of the cylinder, makes a linear movement, as a result of the effect of the inclined plane; a Force F_v in a direction perpendicular to F_s is generated.

A cylinder with a stroke $C = 50\ mm$ is connected to a wedge of height $a = 10\ mm$ with a base $b = 100\ mm$; what will the displacement s in height be?

To find s we use the formula:

$$s = a * \frac{C}{b} \qquad 10\,[mm] * \frac{50\,[mm]}{100\,[mm]} = 5\,N \qquad s = \mathbf{5\ mm}$$

Lets determine the value of s if $a = 5\ mm$ and $b = 100\ mm$:

$$s = a * \frac{C}{b} \qquad 5\,[mm] * \frac{50\,[mm]}{100\,[mm]} = 2{,}5\ mm \qquad s = \mathbf{2{,}5\ mm}$$

Changing the terms of the example: a wedge of height $a = 10\ mm$ and base $b = 100\ mm$ has a displacement $s = 4\ mm$, determine the value of the stroke C of the wedge.

Using the above formula in the reverse order:

$$C = s * \frac{b}{a} \qquad 4\,[mm] * \frac{100\,[mm]}{10\,[mm]} = 40\ mm \qquad C = \mathbf{40\ mm}$$

With $a = 5\ mm$ and $b = 100\ mm$:

$$C = s * \frac{b}{a} \qquad 4\,[mm] * \frac{100\,[mm]}{5\,[mm]} = 80\ mm \qquad C = \mathbf{80\ mm}$$

Halving the height a, the stroke C doubles.

Figure 26

The double wedge

This system allows us to obtain the same Force F_v on two inclined surfaces by applying a minimum value of the Force F_s. In this case the wedge has a section with the form of an isosceles triangle with dimensions of $a = 10\ mm$ and $b = 100\ mm$, with a thrust Force $F_s = 100\ N$, two equal Forces F_v are produced, each 100 N both perpendicular to the applied Force F_s, but one directed upwards and one directed downwards.

$$F_s = F_v * \frac{a}{b} \qquad F_v = F_s * \frac{b}{a} \qquad 100\,[N] * \frac{100\,[mm]}{10\,[mm]} = 1000\ N \qquad F_v = \mathbf{1000\ N}$$

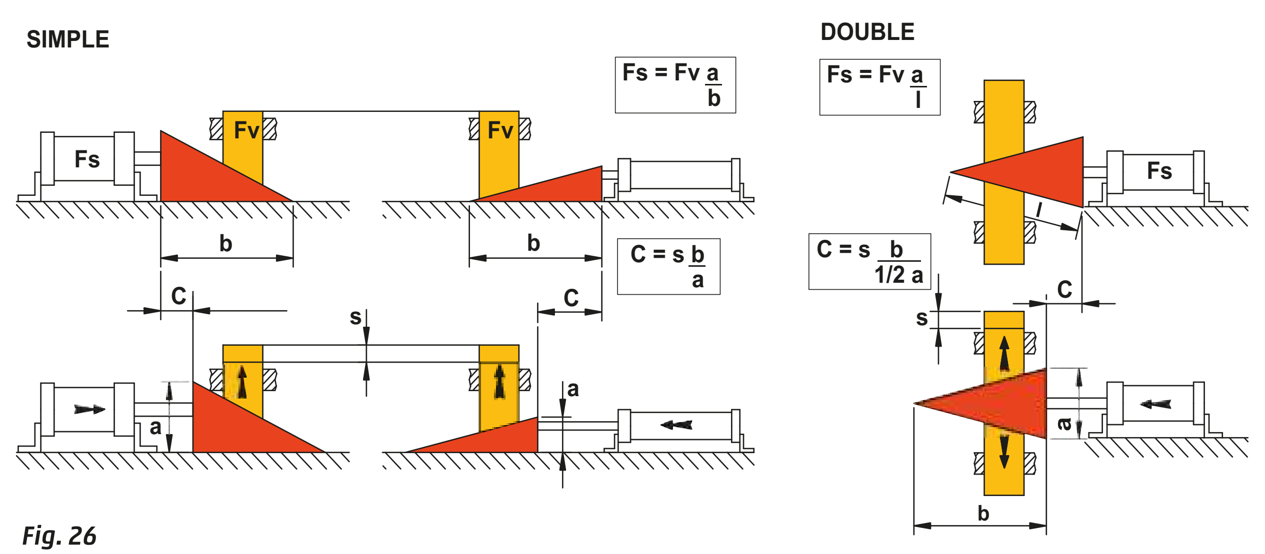


Fig. 26

The figures below show how the wedge can be used.

Figure 27
Pos. A: the sliding friction between load surface F_v and the inclined plane during the lifting phase is transformed into rolling friction by means of a round body supported by an arm, in this way improving the working conditions.
Pos. B: this wedge/lever combination improves the ratio between Force F_s and Force F_v. It also changes the point of application of Force F_v.

Examples of wedge application in equipment

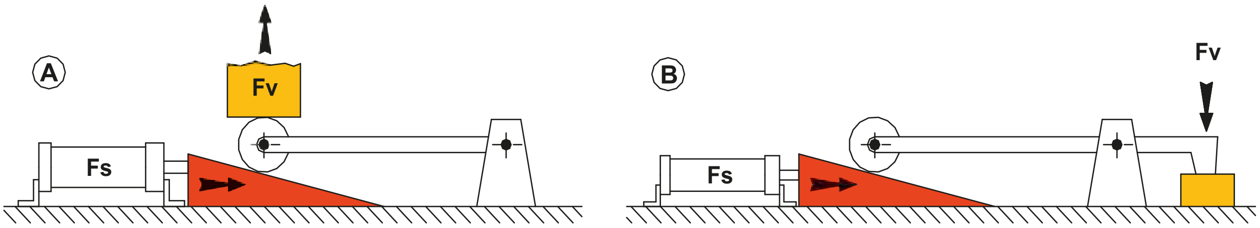


Fig. 27

Rotary cylinders

Figure 28
The rotating cylinder possesses a number of the features discussed in previous chapters where we illustrated how to connect a traditional cylinder to a crank or a gear. The pinion/rack group is an integral part of the rotary cylinder and is connected to the two pistons which each have a magnetic ring in their respective chambers.
The movement of the pistons carries the movement of the rack. The heads are equipped with adjustable end cushioning and angular adjustment screws; there are also set screws on the central body to offset the slack between the rack and pinion. The angles of rotation on these cylinders are normally 90° and 180°.
The rotation angle depends on the length of the rack and the number of teeth of the pinion.
The **torque force** M_t; of the rotary actuator is defined by the distance (in meters) between the axis of the pinion and the rack, in combination with the thrust Force acting on the rack, this value is decisive in the choice of the cylinder. This torque Force expressed *Kgm* or *Nm* is obtained by multiplying the thrust Force of the piston acting on the rack, by the rolling pitch diameter.

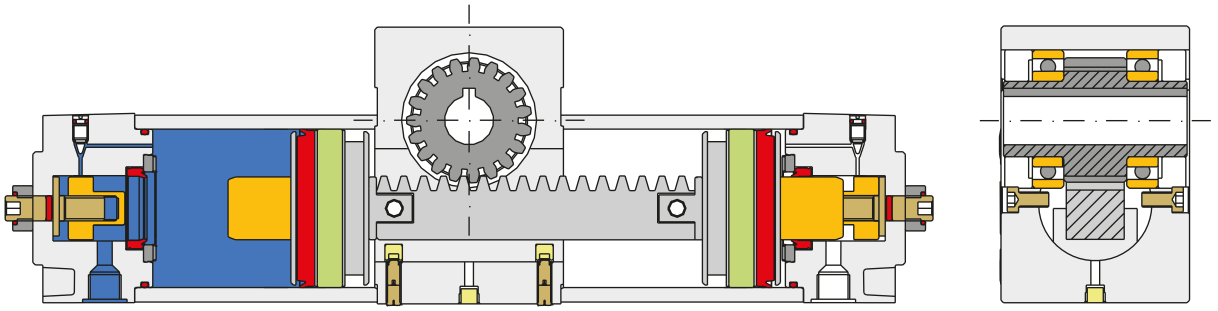


Fig. 28

Figure 29
Pos. 1: a indicates the distance between the axis of the pinion and the axis of the rack, and F_1 indicates the Force developed by the piston, the torque Force of the cylinder is equal to the product of the two values, namely:

$$M_t = F_1 * a$$

The Force is expressed as a derivative of the pressure, as is the torque.

Figure 29
Pos. 2: one end of the arm *b* is connected to the shaft of the pinion while the other bears a weight corresponding to a Force *F*. To ensure that the system remains in equilibrium, with the actuator under pressure and the weight not moving, it is necessary for the two torque forces to remain equal.

$$F_1 * a = F * b$$

In fact, given that the weight corresponding to the Force *F* must be put in motion, the torque force of the cylinder must be greater.

Fig. 29

Figure 30
Pos. 3: lifting a component from a low conveyer to a higher conveyer.
Pos. 4: actuation of a butterfly valve.
Pos. 5: opening of a swing door.
Pos. 6: sorting an item to be discarded, the cylinder from its rest position is ready to stop and move the item to another direction.

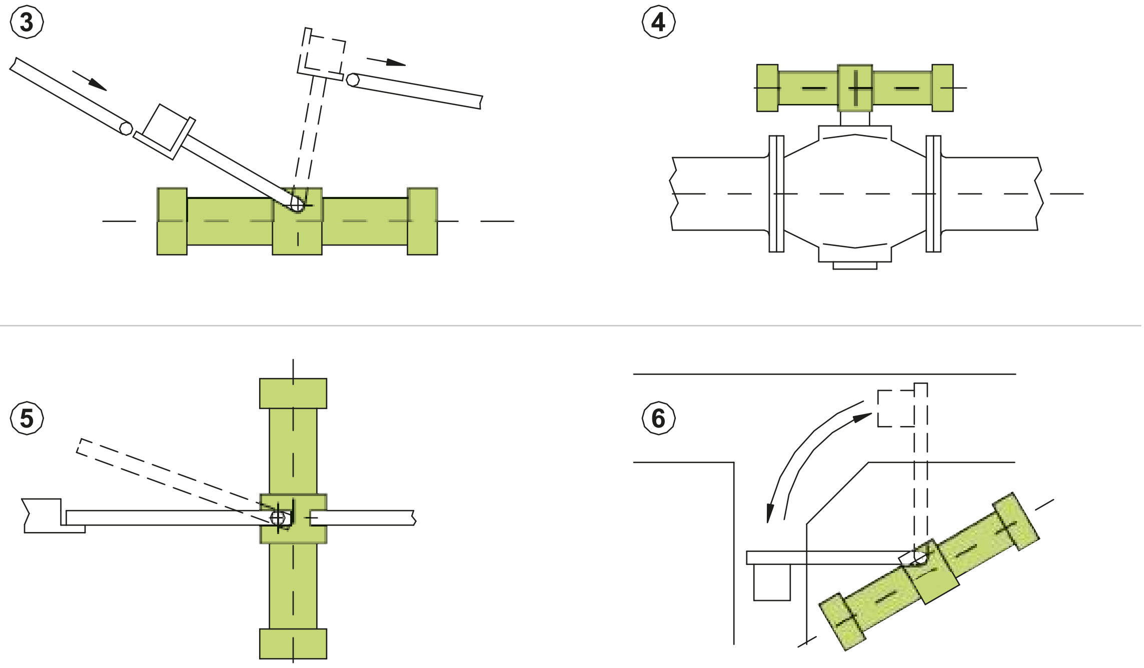


Fig. 30

Magnetic cylinders

In pneumatic circuits, a cylinder is usually equipped with devices which detect the end position of the piston rod/piston. These devices can be operated via the piston rod or the piston. By placing a permanent magnet in the piston, a magnetic proximity switch is able to detect the magnetic field generated.
The orientation of the magnetic field is at its maximum only along the vertical axis, in correspondence with the positioning of the end stroke on the outside of the cylinder. The cylinder must be constructed with non-magnetic materials otherwise they will interfere with the lines of force generated by the magnet.

Figure 31
Pos. 1: construction of a piston with the magnetic ring.
The size, geometry and the distance of the proximity switch from the magnet are crucial for the proper functioning of the system. Too strong a magnetic field can be detected not only in the vertical direction but also in the lateral direction, generating a long contact stroke; too weak a magnetic field may be detected only at the end positions but not during the stroke. The manufacturer of the cylinders will also provide proximity switches adapted to the characteristics of the magnetic field.
Pos. 2: the proximity switch is a special type of electrical switch, which changes the position of the contact in the presence of an external magnetic field. Normally at rest the contact type is **open**, i.e. there is no passage of current. The switches can be mounted on the tie rods or directly to the cylinder profile without any brackets or adapters. The quote *b* indicates the amplitude of the magnetic field, in which the contact of the proximity switch is closed. The hysteresis, given by the quote *H*, may result in a delay of the closing or opening of the contact on the proximity switch. The field of operation, due to hysteresis, is displaced (by a value equal to *H*) in the opposite direction to the movement of the rod/piston.

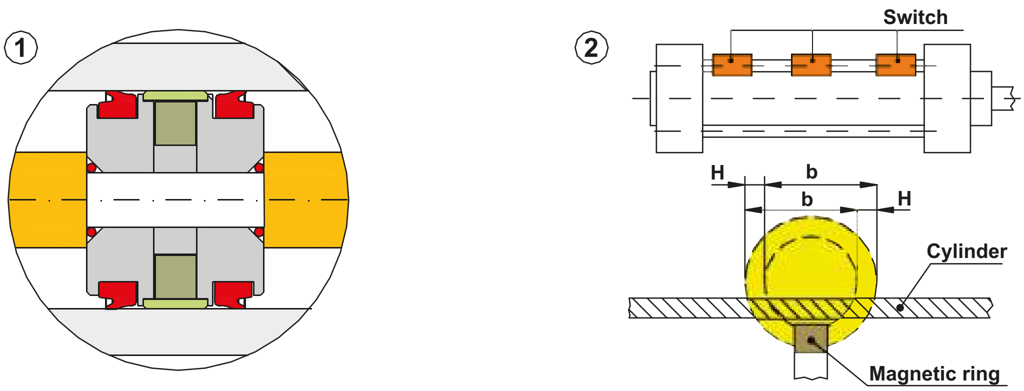


Fig. 31

Figure 32
Behaviour of the switch in positive stroke.
A: the magnetic field begins to act on the switch but the force generated is not sufficient to move the electric contact. (hysteresis *H*).
B: the proximity switch is located in the zone of maximum attraction of the magnetic field; the electrical contact closes and remains closed for the length *b*.
C: the magnetic field moves away from the proximity switch but the strength is still sufficient to keep the contact closed.

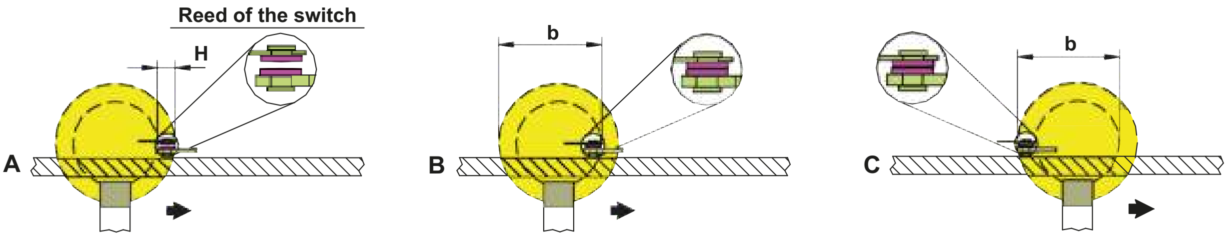


Fig. 32

Figure 33
Behaviour of the switch in negative stroke.
A: the magnetic field begins to act on the switch but the Force generated is not sufficient to move the electric contact. (hysteresis *H*).
B: the proximity switch is located in the zone of maximum attraction of the magnetic field; the electrical contact closes and remains closed for the length *b*.
C: the magnetic field moves away from the proximity switch but the strength is still sufficient to keep the contact closed.

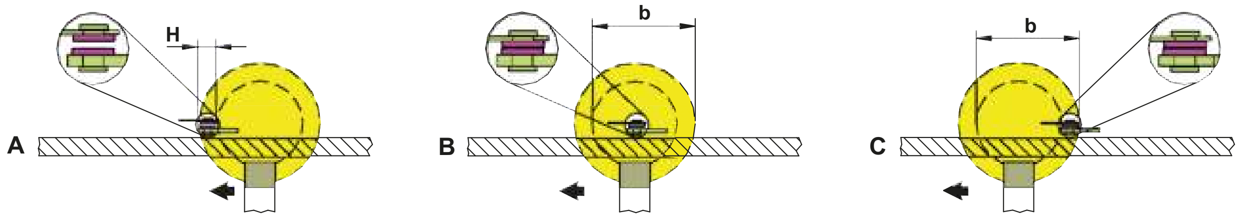


Fig. 33

The contact strokes can be found in the cylinder manufacturer catalogues.

The following information is useful for the use of magnetic proximity switches:

- the life of the switch depends on the load applied and the number of switching operations,
- the maximum current value is related to closed contacts,
- the switch may be influenced by magnetic fields generated by large electrical motors, or electrostatic charges from objects in motion.

Special purpose cylinders

The cylinders we have analyzed, characteristically consist of a single piston rod and a single piston. We examine the different versions and their varying characteristics.

Figure 34
Opposed cylinders
From a standard cylinder it is possible to obtain two positions defined by each stroke of the rod/piston. By rigidly connecting the rear heads of two cylinders, we can achieve:
A: three positions if the stroke lengths are the same
B: four positions if the stroke lengths are different.

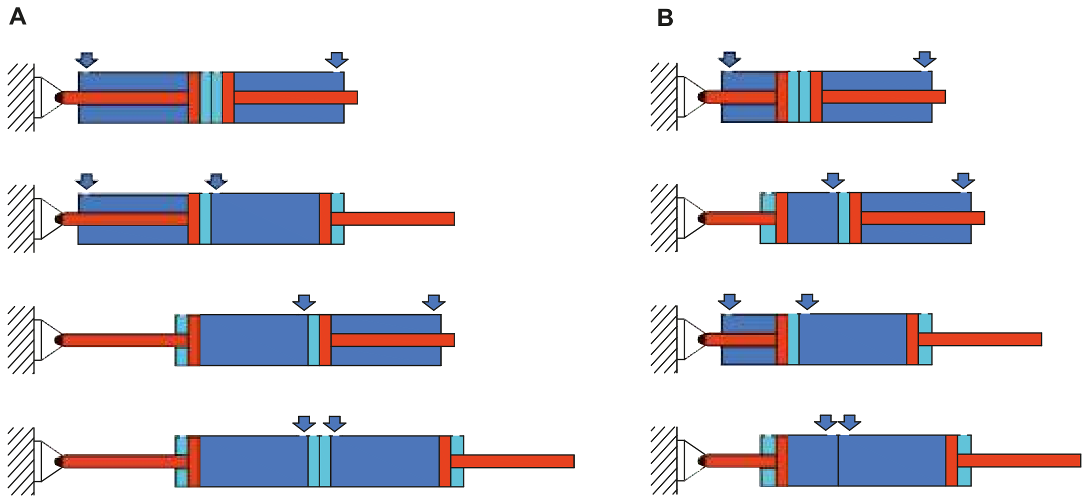


Fig. 34

Figure 35
Tandem cylinders

We have already verified that the Force generated by a cylinder depends on the pressure and the (surface area) diameter of the piston. When a large Force is required but the space available for a cylinder with a large piston is limited, an alternative solution can be cylinders in tandem (tandem cylinders).

The tandem cylinder consists of a single cylinder with two positive and negative chambers and two pistons where the piston rod of the first piston is mechanically connected to the second one. The resulting thrust Force is given, (slightly reduced by the friction), by the sum of the surface areas of the two pistons and the pressure acting on them. Tandem cylinders can have many consecutive pistons and are defined as with 2, 3 or 4 phases based on their number of pistons.

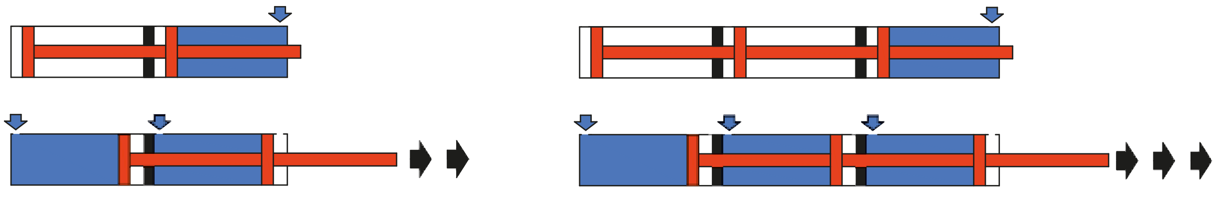


Fig. 35

Figure 36
Multi-position cylinders

When different positions are required at the piston rod piston, the cylinder used is a multiple-position cylinder.

It is comparable to the solution where the first piston pushes the adjacent one, which pushes the one adjacent to it and so on. The cylinder strokes can be all the same, or different. Pneumatically feeding the front chamber of the piston an effect of air spring is created, which repositions all the pistons at the rear end. Maintaining limited pressure on the front chamber and subsequently feeding the rear chambers you can attain various stroke lengths. The same situation occurs in the reverse direction, after exhausting the rear chambers.

It is important to maintain constant pressure (of a relatively low value) in the front chamber of the cylinder to avoid unwanted positions.

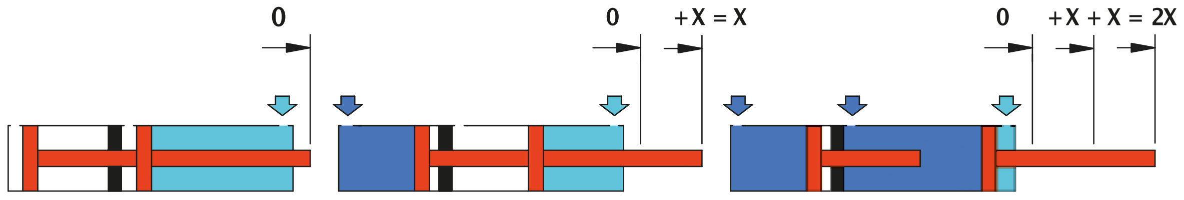


Fig. 36

Figure 37
Rod-less cylinders

In this type of cylinder, there is no rod, but there is an external carriage mechanically connected to the piston inside the cylinder is end block. The end block is cut longitudinally and the seals are made of steel plates, or soft seals with a specific profile. Since there is no rod, the thrust and traction surfaces are perfectly equal and therefore, with the same pressure, the cylinder Force is exactly the same. The benefit of this type of construction is the reduced dimension, compared to that required of a normal cylinder, which doubles its length when the piston rod is extended. These cylinders are mainly used in long stroke applications and where there is a limited space. When the stroke length is short however, this characteristic is not valid.

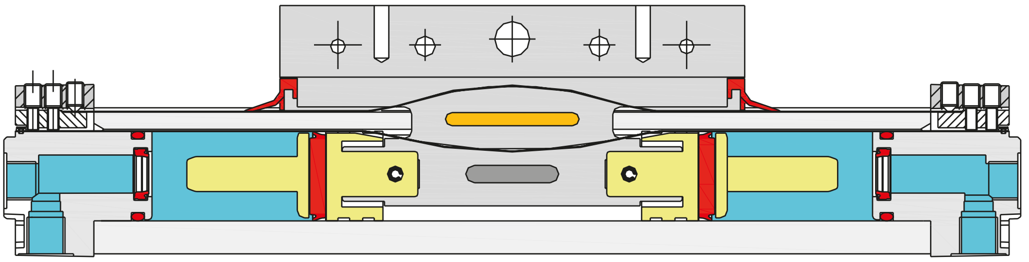


Fig. 37

Cylinder free air consumption

Free air or air at atmospheric pressure is readily available at zero cost. For air to acquire energy in the form of pressure it must be compressed and stored.
The compression process only occurs through the expenditure of another type of energy, often electrical, which has a production cost, contributing to the cost of the pneumatic energy.
The cost of the pneumatic energy is not related to the volume of **compressed air** but to the volume of **free air**.

The amount of free air that the compressor must draw in and compress to the desired pressure is defined as Nm^3 normal cubic meter. Assuming that a compressor with a power of 11 *KW* supplies a quantity of air of 1400 *Nl/min*. that is 84 Nm^3/h (considering a pressure of 10 *bar*), that 1 *KW* of electrical power costs 0,10 € and that the compressor stays active for one hour, the cost for the production of compressed air is:

$$\text{Cost} = 11 * 0{,}10 = 1{,}1\ \text{€/h}$$

Assuming that the pneumatic equipment consume 600 *Nl/min*. → 36 Nm^3/h it means that the compressor keeps running for:

$$36 / 84 = 0{,}43 * 100 = 43\ \%$$

The daily cost of electrical power to produce this quantity of air is:

$$\text{Cost} = 1{,}1 * 0{,}43 = 0{,}473\ \text{€}$$

for 220 working days

$$220 * 8 = 1760\ \text{hours} \qquad 1760 * 0{,}473 = \mathbf{832{,}48\ €}$$

In order to increase the pressure, the compressor must draw in and compress a larger volume of "free air"; the higher the pressure value necessary, the longer the operating time, and consequently the higher the cost.

Figure 38
Consumption Q: is the amount of free air expressed in *Nl* that the compressor must supply to the cylinder to perform a given job.
Q_S: with the piston against the front end-caps the volume to be filled is that corresponding to the positive stroke; its value is determined by the product of the surface of the piston multiplied by the stroke itself. Once the volume is known, we can calculate how many dm^3 of compressed air are contained in a cylinder chamber. With a pressure of 6 *bar* for example, the relative pressure of 6 *bar* corresponds to an absolute pressure (6 + 1) = 7 *bar*.
It is the absolute pressure value that is used when calculating free air consumption.
Q_t: similar to Q_S except that due to the presence of the piston rod, the volume of the negative chamber is lower than that of the positive chamber.
n: number of cycles per minute. This data is necessary to determine the amount of free air that the compressor must provide to the cylinder so that it can perform the operations provided in the unit time. The sum of *Qs* and *Qt*, (i.e. the air flow required for the positive and negative strokes) is to be multiplied by the number of cycles that the cylinder completes per minute. In the case of multiple cylinders operated simultaneously, the respective *Qs* and *Qt* must be summed to calculate the amount of free air necessary.

For an accurate calculation of *Q* consumption, it is necessary to consider any differences in the pressure and the number of strokes (positive and negative) per minute.

Example: cylinder with diameter $D = 32\ mm$

rod $d = 12\ mm$

stroke $C = 200\ mm$

number of cycles $n = 10$ *per minute*

positive chamber supply pressure $p_S = 6\ bar$

negative chamber supply pressure $p_t = 4\ bar$.

Area of positive chamber

$$S_S = \frac{\pi * D^2}{4} \qquad \frac{3{,}14 * 32^2}{4} = \mathbf{803\ mm^2}$$

Area of negative chamber	$S_t = \dfrac{\pi * (D^2 - d^2)}{4}$	$\dfrac{3{,}14 * (32^2 - 12^2)}{4}$	$= \mathbf{690\ mm^2}$
Volume of positive chamber	$V_s = S_s * C$	$V_s = 803\ [mm^2] * 200\ [mm] = 160600\ [mm^3]$	$V_s = \mathbf{0{,}160\ dm^3}$
Volume of negative chamber	$V_t = S_t * C$	$V_t = 690\ [mm^2] * 200\ [mm] = 138000\ [mm^3]$	$V_t = \mathbf{0{,}138\ dm^3}$

Amount of free air required to fill the volume of the two chambers V_s and V_t considering a pressure $p_s = 6\ bar$ and $p_t = 4\ bar$:

$Q_s = V_s * (p_s + 1)$	$Q_s = 0{,}160\ [dm^3] * (6 + 1)\ [bar] = \mathbf{1{,}12\ Nl}$
$Q_t = V_t * (p_t + 1)$	$Q_t = 0{,}138\ [dm^3] * (4 + 1)\ [bar] = \mathbf{0{,}69\ Nl}$

Quantity of air necessary per min

$Q = (Q_s + Q_t) * n$	$Q = (1{,}12 + 0{,}69\ ) * 10 = \mathbf{18{,}1\ Nl\ /\ min}$

With a supply pressure in both chambers of 6 *bar*, the amount of free air is:

$Q_s = V_s * (p_s + 1)$	$Q_s = 0{,}160\ [dm^3] * (6 + 1)\ [bar] = \mathbf{1{,}12\ Nl}$
$Q_t = V_t * (p_t + 1)$	$Q_t = 0{,}138\ [dm^3] * (6 + 1)\ [bar] = \mathbf{0{,}96\ Nl}$

Quantity of air necessary per min

$Q = (Q_s + Q_t) * n$	$Q = (1{,}12 + 0{,}96) * 10 = \mathbf{20{,}86\ Nl\ /\ min}$

In the case of single-acting cylinders, the air consumption is limited to the positive chamber.

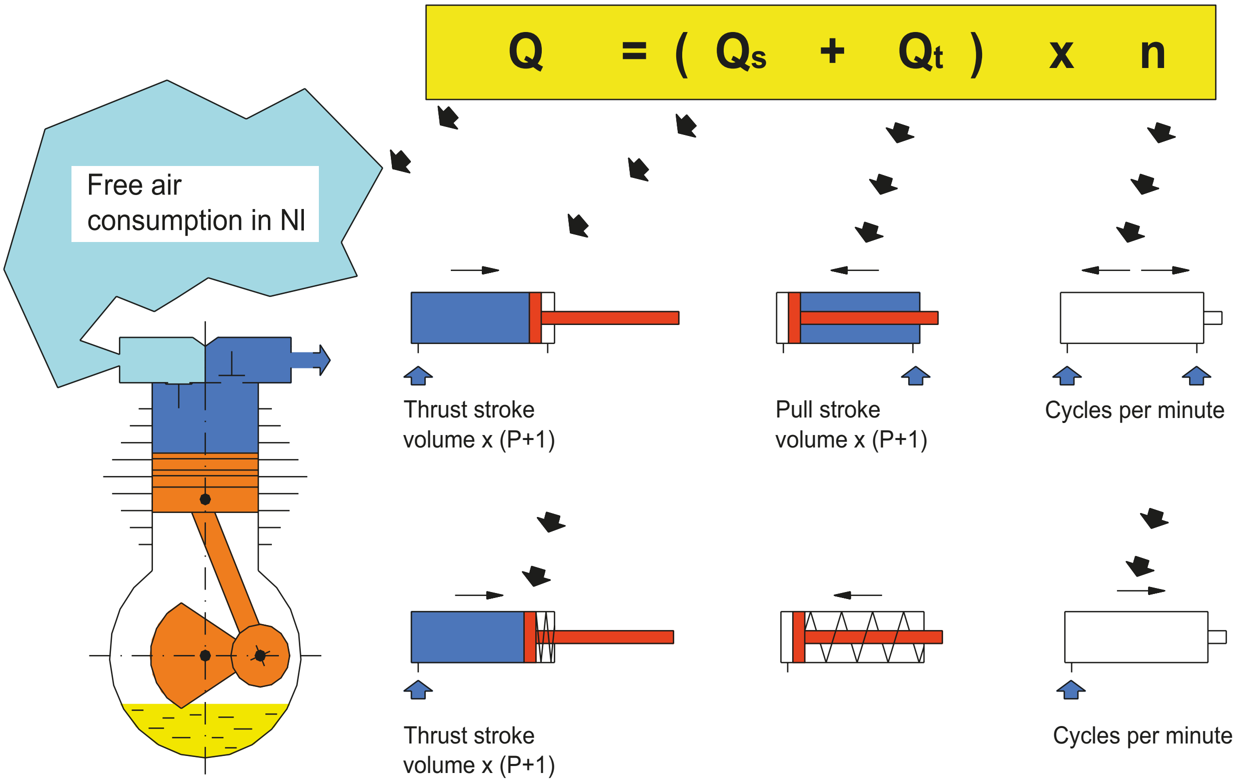


Fig. 38

Required air for a pneumatic cylinder

In previous sections, we analyzed the consumption of free air, i.e. the amount of air that the compressor must produce to constantly supply the pneumatic system, we now analyze the requirement of compressed air by a pneumatic cylinder, i.e. the quantity of air necessary for it to complete a particular operation in the desired time.

Figure 39

Example: a cylinder with diameter $D = 50\ mm$

stroke $C = 250\ mm$

with a pressure $p = 6\ bar$ should execute a positive stroke in *1.5 seconds*.

Depending on the time available we need to size the control valve and the connecting pipes, we **calculate the consumption of compressed air during the positive stroke**.

Thrust surface of the cylinder	$S = r^2 * \pi$	$S = 3{,}14 * 25^2$		$S = \mathbf{1962\ mm^2}$
Volume of the thrust chamber	$V_s = S * C$	$V_s = 1962 * 250$	$V_s = 490.625\ \text{mm}^3$	$V_s = \mathbf{0{,}49\ dm^3}$
	$Q_s = V_s * (p + 1)$	$Q_s = 0{,}49 * (6 + 1)$	$Q_s = \mathbf{3{,}43\ Nl}$	

This quantity of air needs to be inserted in the rear cylinder chamber in a time $t = 1.5\ s$ the required flow Q_{rs} towards the control valve is:

$$Q_{rs} = \frac{Q_s}{t} \qquad Q_{rs} = \frac{3{,}43}{1{,}5} \qquad Q_{rs} = 2{,}29\ Nl/s \qquad Q_{rs} = \mathbf{137\ Nl\ /\ min}$$

The average speed of the cylinder is:

$$V = \frac{C}{t} \qquad V = \frac{250}{1{,}5} \qquad V = \mathbf{167\ mm\ /\ s}$$

If we reduce the stroke time to 1 second, the request of air Q_{rs} would be:

$$Q_{rs} = \frac{Q_s}{t} \qquad Q_{rs} = \frac{3{,}43}{1} \qquad Q_{rs} = 3{,}43\ Nl/s \qquad Q_{rs} = \mathbf{206\ Nl\ /\ min}$$

By increasing the speed the request of air increases, therefore the control valve should be sized appropriately.

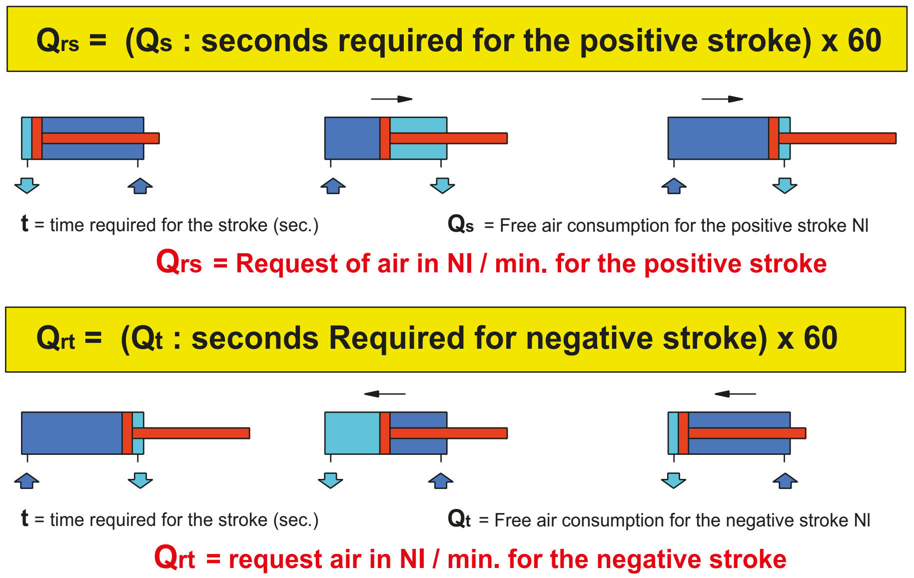


Fig. 39

Hydrochecks

The seals of the pneumatic cylinders may not be fully compatible with the oil used in hydraulic brakes, for this reason, the hydrochecks are independent of the pneumatic cylinder.
The hydrocheck consists of a cylinder with a relative compensation tank and can be equipped with:

Flow regulators, for adjusting the speed in:
- thrust
- traction
- or in both directions.

Valves:
- Skip (for maximum acceleration)
- Stop (for blocking the movement)

Both of these valves, by-pass the speed settings.

Figure 40
Pos. 1: the oil present in the two chambers is located in a closed circuit and flow control valves allow the possibility of adjusting the speed in both directions. The reserve of oil in the container compensates for the difference in volume existing between the front and rear chamber of the hydrocheck.
Pos. 2: example of connection of the hydrocheck with a pneumatic actuator. The rods are mounted on the same axis.
Pos. 3: example of connection of the hydrocheck with a pneumatic actuator. The rods are parallel.
Pos. 4: example of adjusting the speed of advancement from the tip of a drill.
The approach stroke to the work piece to be drilled is rapid, the drilling operation is slow and regulated.
A: the rod is at the negative end-stroke
B: the piston rod of the pneumatic cylinder has covered the approach stroke (this length of the stroke is adjustable by means of regulation nuts) without the adjustment of the hydrocheck.
C: from this position and throughout the rest of the stroke, the two rods move together. The pneumatic cylinder is the "engine", the unidirectional flow regulation valve mounted on the hydrocheck regulates the speed during the drilling phase. This speed regulation, being made with a non-compressible fluid (oil) is more precise than a pneumatic alternative.

On the return stroke, the piston rod of the pneumatic cylinder also re-positions the rod of the hydrocheck.

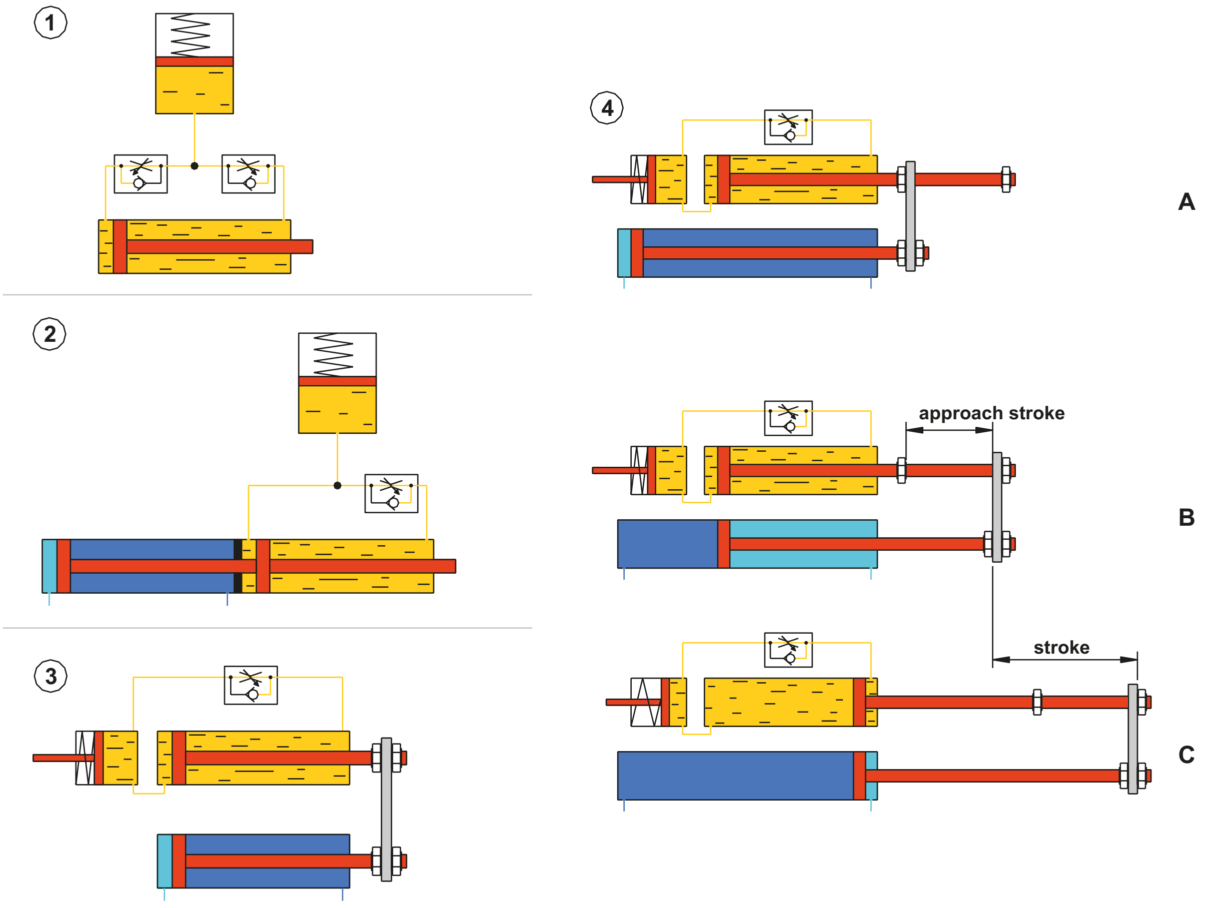


Fig. 40

Pressure booster

Where large forces are required, for example for cutting and/or bending operations, cylinders with large diameters – or Tandem cylinders can be used. In both cases, problems with space may be an issue, a possible solution is to increase the supply pressure, this can be achieved through use of the pressure booster.

The pressure booster has a similar function to two opposing cylinders joined by the piston rod; the movement of these cylinders is oscillating. The central part of the Pressure Booster is fed through a pressure regulator, the two sides by a 5/2-way control valve. The oscillating movement is determined automatically by the internal limit switches that invert the state of the 5/2 - control valve once the piston has reached the end position.
The pressure increase is obtained, as the sum of areas on the thrust side is greater than that of the resistant surface, therefore the volume of the resistant chamber continues to decrease and as a result the pressure increases.

Figure 41
Pos. A: the pressure booster is fed by compressed air, the left piston is in the positive end position, the right piston is at its negative end position, and its relative chamber is exhausted. The pressure regulator feeds compressed air into the central part. The two generated Forces, being in opposite directions, cancel out each other.
Pos. B: the left piston activates the limit switch integrated in the central block that reverses the 5/2-way valve, the right chamber is pressurized, while the left is exhausted. The pressure in the negative chamber of the piston to the right increases, when this pressure exceeds the spring setting of the integrated unidirectional valve, this air exits through the outlet **U**. The unidirectional valves prevent the exhaust through the regulator.
Pos. C: the right piston has reached the positive end position and activates the limit switch that reverses the 5/2-way control valve.
Pos. D: the 5/2-way control valve has switched, the left chamber is pressurized, while the right is exhausted.
The pressure in the negative chamber of the piston to the left increases, when this pressure exceeds the spring setting of the integrated unidirectional valve, the air exits through the outlet **U**. The unidirectional valves prevent the exhaust through the regulator. The piston moves towards the right since the thrust surfaces are greater than the surface on the resistant side. When the piston arrives at the stroke end, the cycle repeats automatically.

The ratio between the inlet pressure and the outlet is normally 1:2 even if different values are possible.

Assuming that: the surface of a piston on the outer side is $S_e = 20\ cm^2$

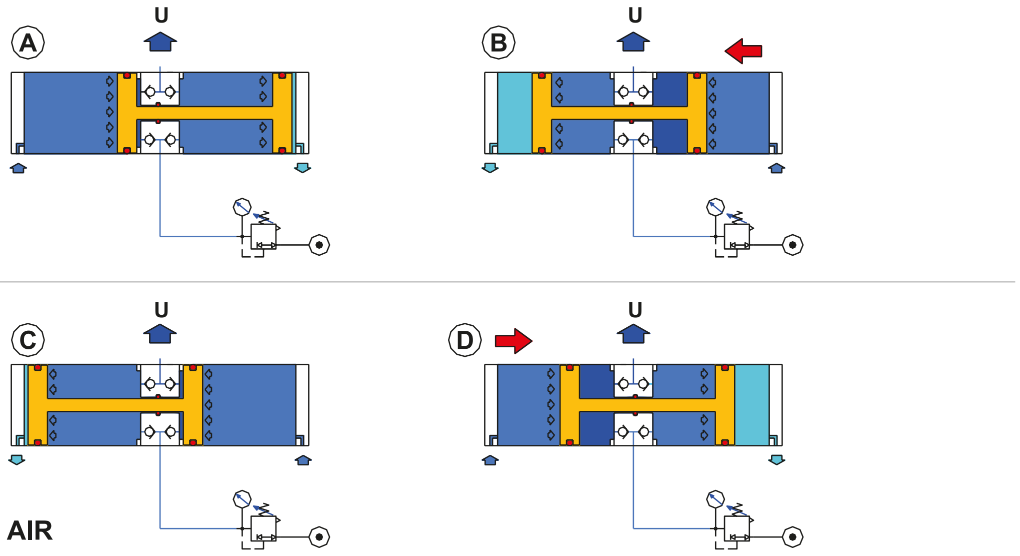
that of a piston on the rod side $S_s = 16\ cm^2$

working pressure $p = 6\ bar$

Calculate the value of the outgoing pressure p_u:

$$F = (S_e + S_s) * p \qquad F = (20 + 16) * 6 \qquad F = \mathbf{216\ kg}$$

$$p_u = \frac{F}{S_s} \qquad p_u = \frac{216}{16} = 13{,}6 \qquad p_u = \mathbf{13{,}6\ bar}$$



AIR
P = 6 bar
$S = 20\ cm^2 + 16\ cm^2 = 36\ cm^2$
F = S x P = 36 x 6 = 216 Kg (2160 N) P = F : S = 216 : 16 = 13,5 bar

Fig. 41

CHAPTER 4
VALVES

Valves

The significance of the term valve depends on the technical application for which the valve is used.
Some examples in different fields of use and function:
Electric: serves to interrupt the passage of electric current when it reaches excessive values.
Motor: they make it possible to enact the phases of an internal combustion engine: intake, compression, combustion, and exhaust.
Thermostatic: prevent reaching high pressures and/or high temperatures inside steam boilers.
Pneumatic: control and regulate the value of the flow, pressure and the direction of the compressed air.
In the pneumatic field, valves can be:

Figure 1
Phase A: directional
These valves open, close or divert the flow of compressed air, so that the cylinder assumes a different position with respect to past position.
Phase B: flow or Pressure Regulation
These valves alter the physical characteristics of the compressed air. The adjustment can be made either on the pressure with "pressure regulation valves", or on the flow with "flow control valves". To adjust the speed of one or both strokes of the cylinder, it is necessary to insert the flow control valve between the distribution valve and the cylinder. By varying the amount of compressed air in the exhaust, the time needed to empty the chambers of the cylinder increases or decreases respectively. The pressure regulation valve is located at the inlet of the distribution valve and is used to regulate the force of the cylinder.
Phase C: interception
These valves block and/or modify the path of compressed air. The valve can prevent the passage of compressed air, keeping it blocked inside the chamber or divert the passage, enabling a quicker way of exhaust.

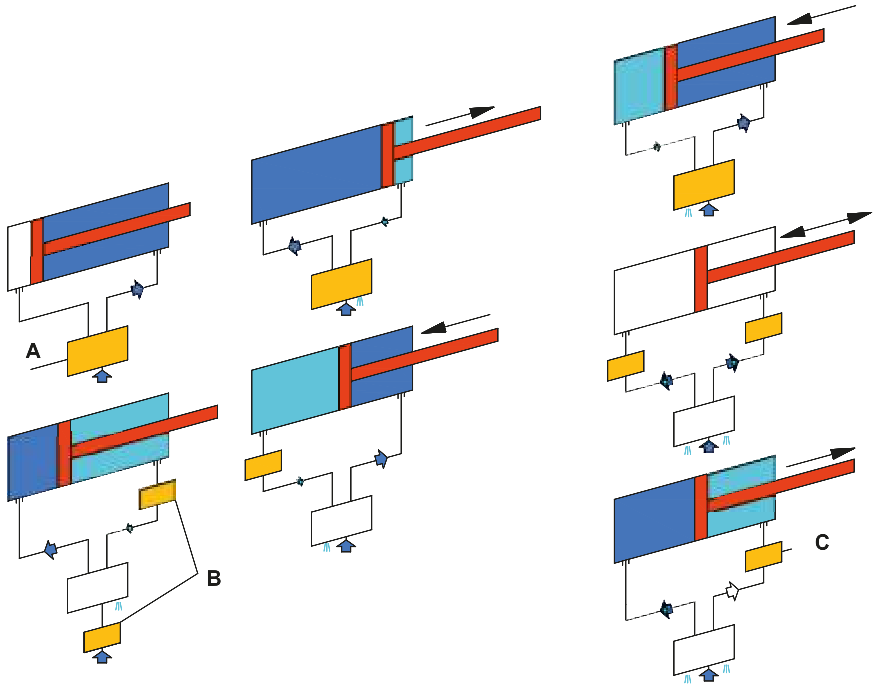


Fig. 1

Classification of the valves

The choice of a valve depends on several parameters; such as the number of positions, ways and method of activation/piloting.

Numbers are used in the classification of valves to identify the number of ways and positions. For example, the term **3/2** indicates a **3**-way, **2**-position valve. The first digit represents the number of **ways**, usually 2, 3 or 5, the second indicates the number of **positions**, usually 2 or 3.

The valves are depicted by a graphical pneumatic symbol, whereby each position a valve can assume is represented by a square. A valve with two positions is indicated by two illustrative squares adjoined and a valve with three positions has three squares adjoined.

Each square contains symbols; the arrow represents the direction of the compressed air flow in that particular position, the "T" represents the blockage of the air passage in that position.
The symbol gives no indication of the size.

Figure 2
Movement of a double acting cylinder.
Phase A: the arrow with the apex pointing upwards indicates the compressed air supplied to inlet 1 of the valve is directed towards the outlet 4 connected to the positive chamber (dark blue colour) of the cylinder. The arrow with apex pointing downwards indicates that the compressed air present in the negative chamber (blue colour) of the cylinder through the valve from the outlet 2 will direct towards the exhaust 3.
Phase B: the arrow with apex pointing upwards indicates the compressed air supplied to inlet 1 of the valve is directed towards the outlet 2 attached to the negative chamber (dark blue colour) of the cylinder. The arrow with apex pointing downwards indicates the movement of the compressed air present in the positive chamber (blue colour) of the cylinder through the valve from the outlet 4 will direct towards the exhaust 5.
Single Acting Cylinder.
Phase C: the arrow with the apex pointing upwards indicates that the compressed air supplied to the inlet 1 of the valve is directed towards the outlet 2 connected to the positive chamber (dark blue colour) of the cylinder.
Phase D: the chamber previously under pressure must be discharged; we can use a valve with fewer ways than in the previous case.
Pressurization of a tank.
Phase F: the arrow with the apex pointing upwards indicates that the compressed air supplied to input 1 of the valve is directed towards the outlet 2 connected to the tank.
Phase G: the arrow has been replaced by a plug, there is no passage of compressed air from inlet 1 to outlet 2, the tank remains pressurised.

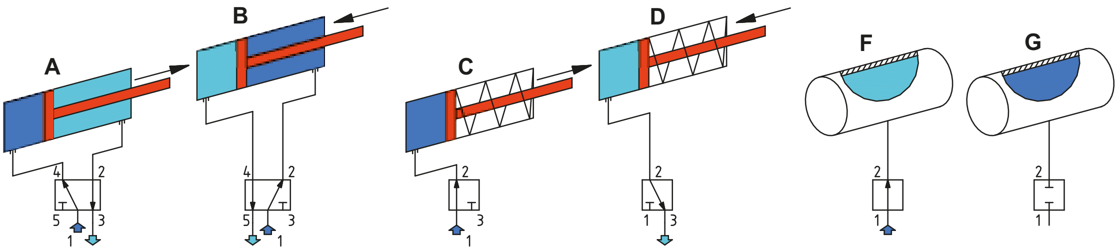


Fig. 2

Figure 3
Pos. 1: 5/2-way valve
The squares **A** and **B** indicate the two positions that the valve can assume, the direction of flow is indicated by the arrows. In addition to the indicated direction of the flow, and regardless of the number of positions, the arrows also indicate the number of connections to the valves, their definition is:

Connection	**1**	**inlet** of the compressed air
Connection	**2**	**outlet** predefined or at rest
Connection	**3**	**exhaust** port of outlet 2
Connection	**4**	**outlet** obtained by controlling the valve
Connection	**5**	**exhaust** port of outlet 4

Pos. 2: 3/2-way valve
The squares **C** and **D** represent the two distinct valve positions.

Connection	**1**	**inlet** of the compressed air
Connection	**2**	**outlet**
Connection	**3**	**exhaust port** of outlet 2

Pos. 3: 2/2-way valve
The squares **F** and **G** represent the two distinct valve positions.

Connection	**1**	**input** of the compressed air
Connection	**2**	**outlet**

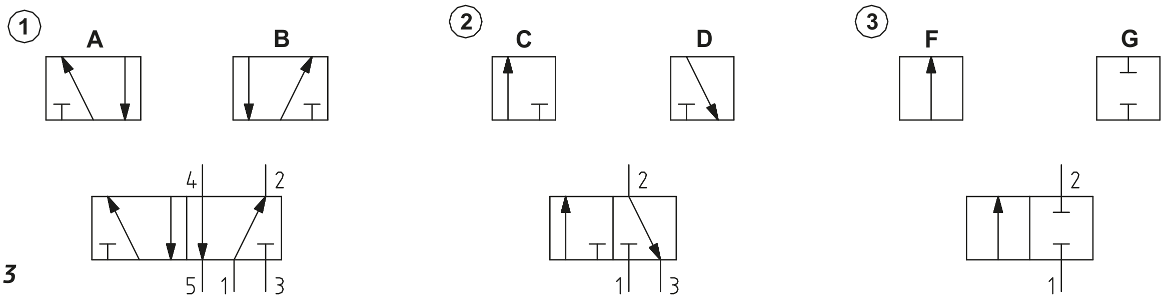


Fig. 3

Poppet valves

The design principle of pneumatic valves is not a function of the number of ways or the number of positions, but depends on parameters such as the area of use, the flow rate, the size etc.
The number of ways may be: 2, 3, 4, 5.
The positions may be: 2 or 3; there are valves with a higher number positions but they have a very limited use.
The different traditional types are: **poppet valves, spool valves, diaphragm valves, disc valves**.

Some valves are better adapted to a specific function; for example, diaphragm valves with a 2/2-way function are more frequently observed than 5/2-way.

The valves may be defined as: **Normally Open (NO) or Normally Closed (NC)**
NC or NO indicates whether or not there is passage of compressed air from inlet 1 to outlet 2 of the valve in the rest position. The poppet and spool valves are those used most frequently in the pneumatic circuit from the valves indicated above.

Figure 4
Pos. 1: 3/2-way valve NC.
The poppet is the component indicated by the letter **B**. Its rest position is given by the mechanical spring below the poppet, by pushing it upwards allows for the seal (coloured in red) to seal, i.e. prevents the passage of the compressed air from inlet 1 to outlet 2. The upper poppet encloses a spring which separates the part **B** from **A**, this arrangement allows outlet 2 to be in communication with exhaust 3.
The valve is activated by pushing the pin **A** downwards: during its movement while coming into contact with **B**, it closes the exhaust 3, then, by compressing the spring below the poppet **B**, opens the passage between the inlet 1 and outlet 2.
Removing the activation force from the pin **A**, the springs re-assume their initial size returning the valve to its normal (non-activated) closed position.
Pos. 2: 3/2-way valve NO.
Here the function is inverted compared to the normally closed valve.
At rest position, the seal **D** is not in contact with the poppet **B**, the compressed air at the inlet 1 is free to move towards the outlet 2 and the seal **C** blocks the exhaust port 3.
The valve is activated by pushing the pin **A** downwards: during its movement, the seal **D** comes into contact with the poppet **B** closing the passage from the inlet 1 to outlet 2, with the lowering of poppet **B** the seal **C** detaches itself from the seal on the valve body, opening the passage of exhaust air from the outlet 2 to the exhaust 3.
The poppet valves, and in particular those which are mechanically controlled, include an extra stroke that allows for a safety margin to avoid the peak load that could damage the valve, this in addition to the stroke required to open/close the valve. By not completing the full stroke of the pin **A**, there is a reduction of flow.
On the pneumatics symbol, the location of the numbers, (and in this case also the return spring), are indicated on the square that identifies the rest position of the valve.
Pos. 3: 5/2-way valve.
This valve is constructed by placing the internal components of the 3/2-way **NC** and 3/2-way **NO** valves side by side in one body, channelling the inputs into a single connection. In 5/2-way valves NC or NO versions do not exist because the input 1 is always open in communication with one of the two outlets 2 or 4.

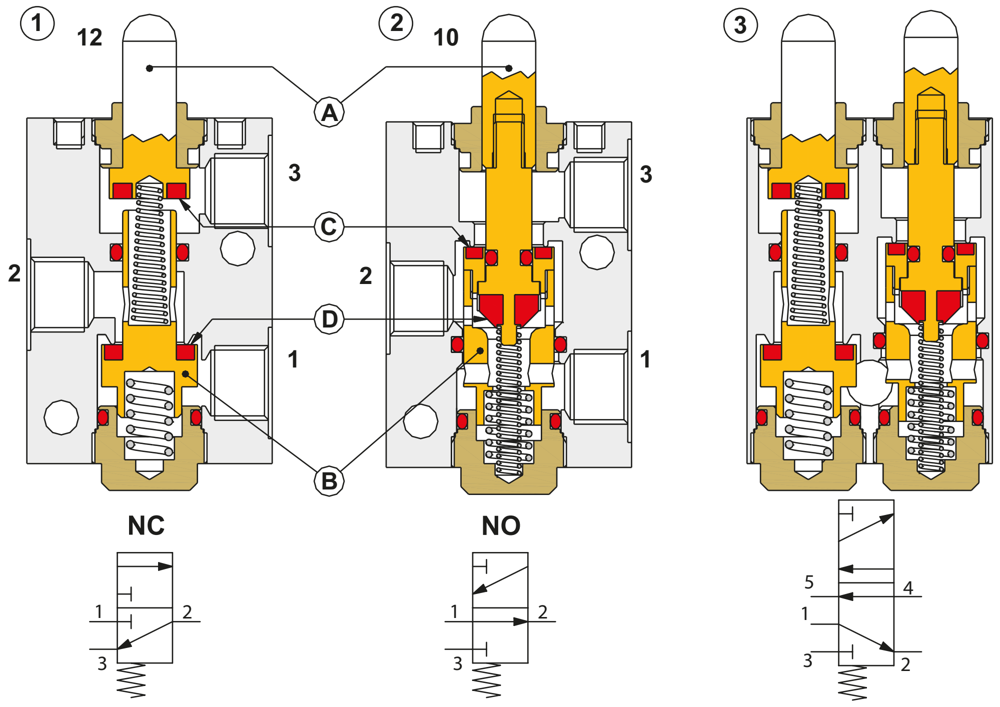


Fig. 4

The function of a 3/2-way NC poppet valve

The illustration below demonstrates the internal workings of a 3/2-way NC valve during the three different phases of a working cycle: rest, intermediate, and activated.

Figure 5
Rest position.
Pos. 1: in this phase, there is passage between the outlet port 2 and exhaust port 3 due to the thrust of the spring positioned between the actuation pin **A** and plunger **B**. Through this action, the compressed air coming from outlet 2, is discharged through exhaust 3. The plunger **B** is maintained in position through the thrust of the lower spring that closes the passage of air coming from inlet 1.
Intermediate position.
Pos. 2: in this phase, the valve has not yet reached the final position: the actuation pin **A** is lowered, and by coming into contact with the plunger **B**, closes exhaust 3. In this phase the plunger **B** has not yet reached its end position so there is not yet a passage of air from inlet 1 to the outlet 2. This intermediate stage is referred to as "closed center" as all ports are isolated from each other.
Activated position.
Pos. 3: in this position, the stroke of the actuation pin **A** and plunger **B** is complete: the actuation pin **A** has not only closed the passage as previously observed, but also pushed down the plunger **B** towards its end position thus opening the passage between inlet 1 and the outlet 2. The valve is maintained in this state for as long as the actuation pin **A** is depressed by the action of an external force.

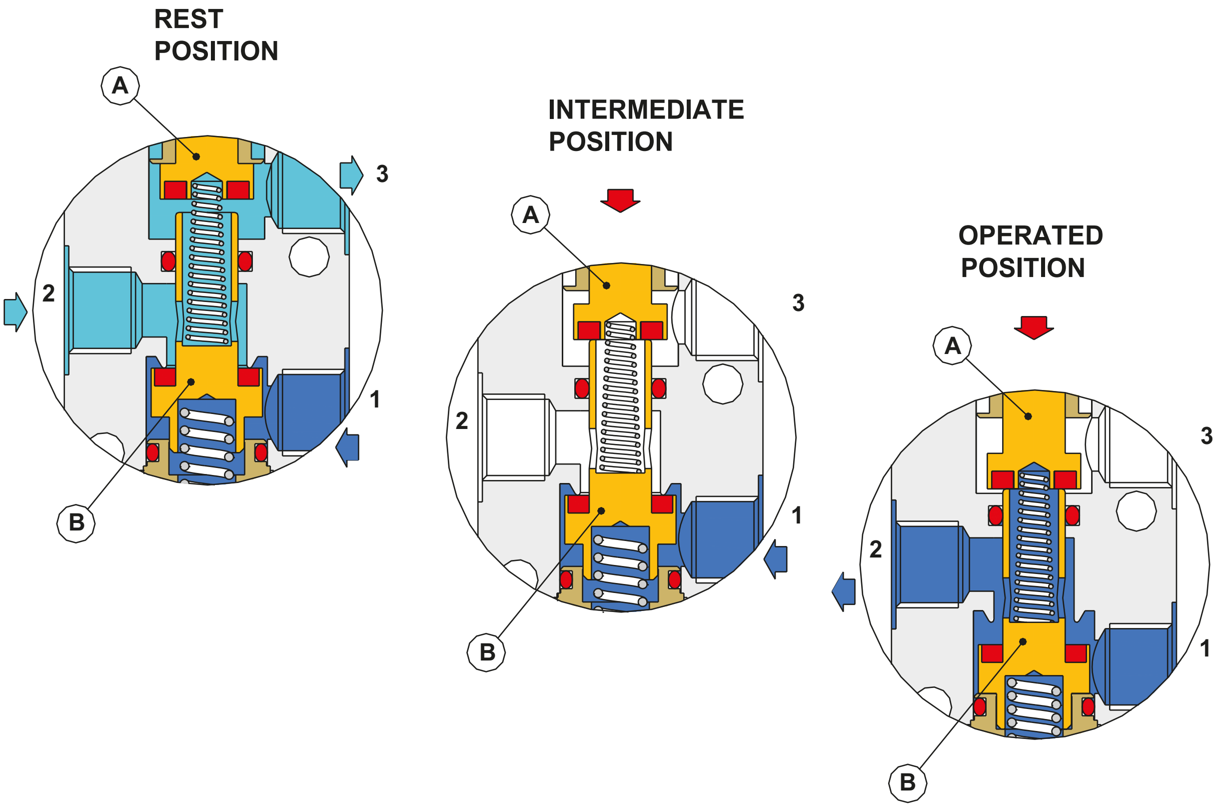


Fig. 5

Return to rest position.
When the actuation force is removed from the actuation pin, the spring positioned below the plunger **B**, raises both the plunger **B** and actuation pin **A**, inlet 1 is closed, and we return back to the "closed centers" phase.
Subsequently, the spring between the actuation pin **A** and plunger **B**, raises the actuation pin **A** and opens the passage between the outlet 2 and exhaust 3 so compressed air exhausts into the atmosphere. The valve is then returned to the rest position.

With this type of plunger, the incoming compressed air can only enter through inlet 1; this feature is illustrated by the pneumatic symbol that identifies one direction only for the flow of the compressed air.
A possible air supply via the connections 2 or 3 would not assume the function of NO, in fact the plunger **B** would be pushed down by the air pressure, also opening the passage through port 1.

The function of a 3/2-way NO poppet valve

As with the 3/2-way NC valve presented on the previous page, we observe the operation of a 3/2-way NO poppet valve in the illustration below.

Figure 6
Rest position.
Pos. 1: in this position, there is a passage from inlet 1 to outlet 2 due to the thrust of the small cylindrical spring acting on the plunger **A**. The cartridge **B**, due to the effect of the seal **C** and the spring with a greater diameter, simultaneously closes the passage towards the exhaust 3. The compressed air is free to flow from inlet 1 to outlet 2.
Intermediate position.
Pos. 2: in this phase, the valve has not yet reached the final position: the plunger **A** is depressed and the seal has closed the passage between inlet 1 and outlet 2 through contact with the plunger **B**, and exhaust 3 is still closed. This intermediate stage is called "closed center" as all ports are isolated from each other.
Activated position.
Pos. 3: in this position, the activation is complete: cartridge **A** and plunger **B** of the poppet have continued their movement until the complete opening of the passage from outlet 2 to exhaust 3. The valve is kept in this state as long as an external force depresses the plunger **B**.

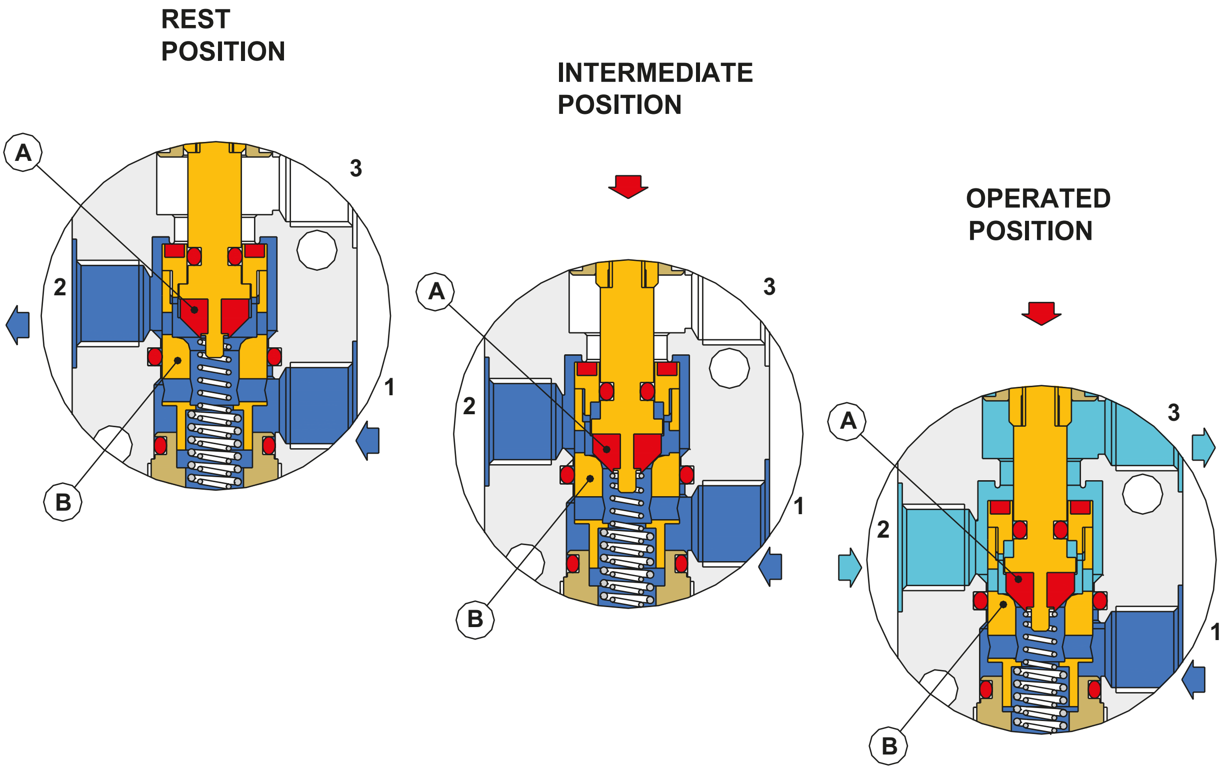


Fig. 6

Return to rest position.
When the actuation force on the plunger **B** is released, the cylindrical spring with a larger diameter raises both the plunger and cartridge **A**, this is the "closed centers" state.
The smaller spring then raises the plunger **A** opening the passage between the inlet 1 and outlet 2. The plunger **B**, due to the seal **C**, closes the passage to the exhaust 3. The valve returns to rest position.

Also with this type of poppet design, air supply is only possible from port 1, this feature is illustrated by the pneumatic symbol that identifies a defined direction for the passage of the compressed air.

Manual operation of poppet valves

The devices used to manually control the valve are categorised as **bistable** or **monostable** depending on the function within the circuit. The light switch, and the doorbell of the house, are two examples which illustrate these two types of devices: the first is bistable as it keeps the position of the light on or off; the second is monostable because it allows the bell to ring only when pressing the button.

Manual Operation:

Figure 7
Monostable push button operator, spring return.
The force transmitted by the push button depresses the poppet plunger, this allows the passage of air if the valve is NC type or its interruption if NO and this will continue as long as the push button is pressed. The repositioning is performed by a spring within the valve which releases the key.

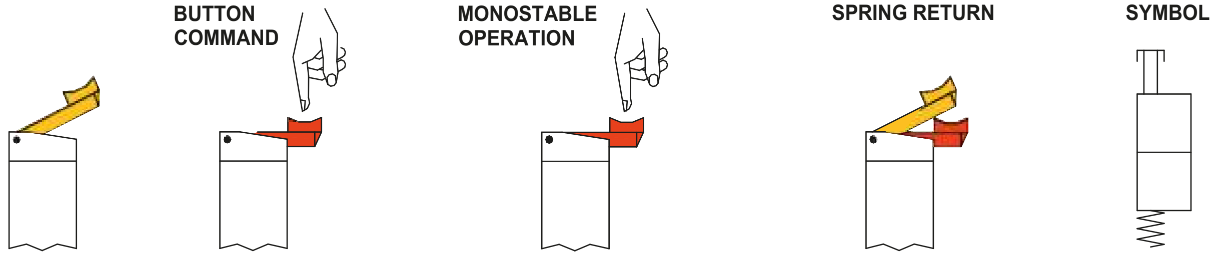


Fig. 7

Figure 8
Monostable lever operator, spring return.
The valve is operated by moving the lever through its arc of movement. The operator must hold the lever in the operating position for the duration of the action; this achieves the passage of compressed air if the valve is NC or its interruption NO. When the lever is released, a spring will return the valve to its initial position. The valve is of the monostable if type.

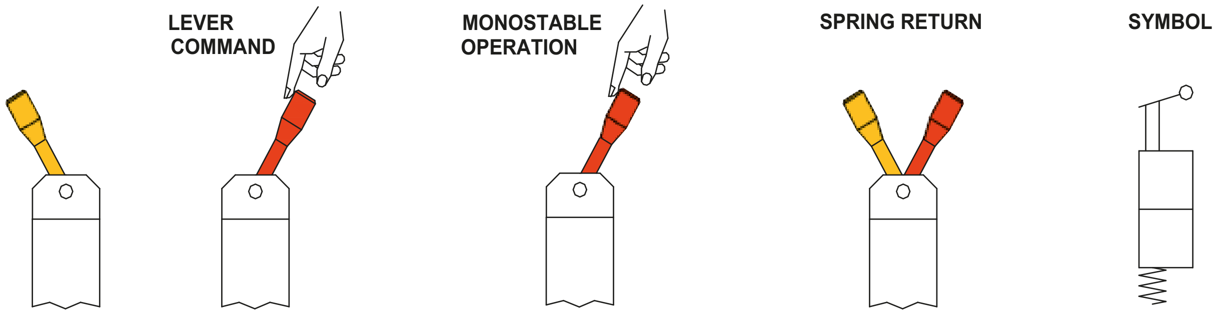


Fig. 8

Figure 9
Lever control, bistable operation, manual repositioning.
The valve is operated by moving the lever throughout its arc of movement, once the end position is reached, the operator may release the lever, this allows the passage of the compressed air if the valve is NC or its interruption if NO. The repositioning is performed manually by returning the lever to the initial position.

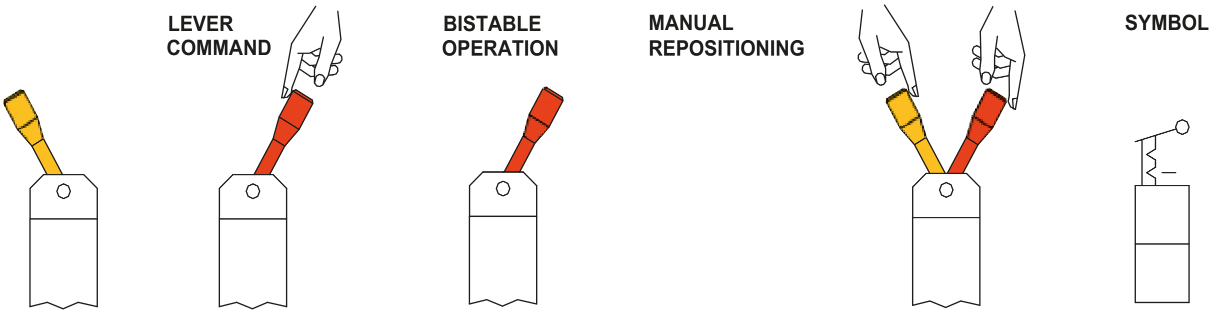


Fig. 9

Mechanical operation of poppet valves

In an automated system human intervention is limited to the start-up or to resolve any emergencies. The progress of the sequence is determined and controlled by "switch" valves that release a signal when activated. Their operation - in this case "mechanical", is determined by attainment of the desired positions by the bodies in motion, for example cylinders.

Some types of mechanical control.

Figure 10

Pos. 1 and **2: roller lever, monostable operation, spring return.**

The drive requires a continuous pressure on the roller lever and allows the passage of the compressed air if the valve is NC or its interruption if NO. Such passage continues for as long as the drive continues.

The roller lever control is used when the object in motion (cam), which drives the mechanical device of the limit switch, has a direction of movement perpendicular to the valve axis. For correct assembly, the limit switch must be oriented so that the rotation of the lever is in the same direction as the movement of the cam. The return of the valve is set using an internal spring.

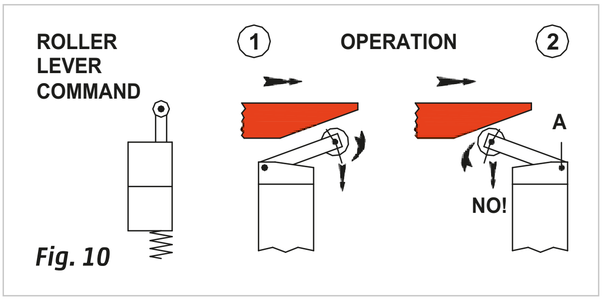


Fig. 10

Figure 11

Pos. 1 and **2: one-way roller lever control, monostable operation, spring return.**

Corresponds to the roller lever, but the particular conformation of the drive makes it unidirectional, the switching only occurs in one of two directions.

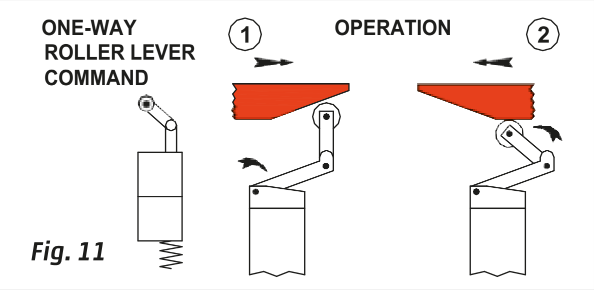


Fig. 11

Figure 12

Front control, monostable operation, spring return.

This type of command is used when the object in motion, which activates the mechanical device of the limit switch, is moving parallel to the axis of the valve. At the end of the movement, it must be ensured that the object in motion does not activate the front control above the maximum allowed value, given by the sum of the stroke and the extra-stroke.

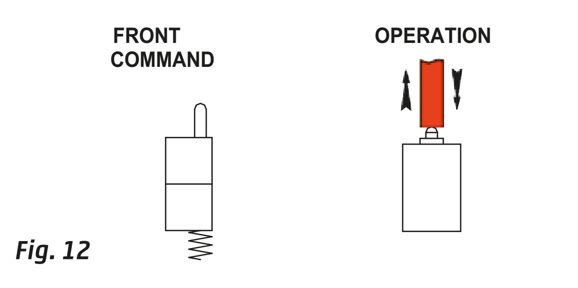


Fig. 12

Examples of activation:

Figure 13

A: with the object in motion (cam) having returned in the starting position, only the first limit switch remains activated, the others are at rest.

B: with the cam in the intermediate position, it reaches the limit switch with a mechanical device operated by a unidirectional roller lever and activates it for the entire length of the cam.

This limit switch is at a lower position because the mechanical control device of a unidirectional lever roller is larger.

C: with the cam in the end position, it activates the last limit switch mounted in the direction opposite to the first cam and keeps it in operation.

D: during the return stroke, the cam, which is in an intermediate position, lowers the only part of the lever in which the limit switch has a one-way function (the knee), thus avoiding switching.

E: with the cam having returned to the starting position, it only keeps the first limit switch activated.

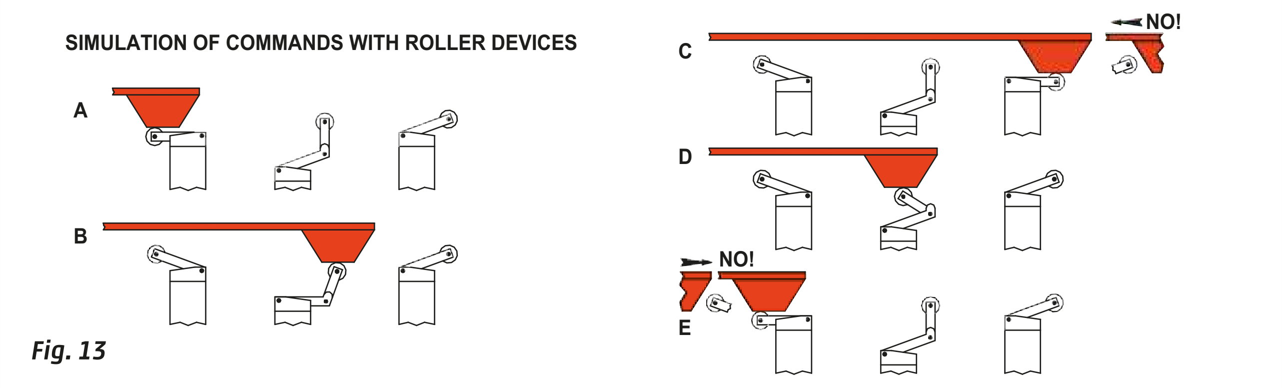


Fig. 13

Mini poppet valves

In these types of mini-valves, in order to limit the size, not all of the connections have threaded ports or are designed for the insertion of the tube. It is also possible that both the threads and tube connection cartridges typically have M5 dimensions (for threads) and cartridges for a 4 *mm* tube diameter.

Figure 14
Model: 3/2-way NC
The tube connections to the inlet 1 and outlet 2 are located in the body of the valve. The exhaust port 3 is obtained by the passage **B** located in the plunger stem "**A**".
The compressed air from inlet 1 acts on the seal "**C**" which, by elevating, closes the passage through the plunger stem **A**. The outlet 2 and the exhaust port 3 are in communication through the passage **B** inside the plunger stem **A**.
The drive of the mini-valves is achieved by lowering the plunger stem **A** with a short stroke. The end part of the plunger (which acts as a shutter) by pushing the seal **C**, closes the exhaust 3 through the passage **B**, and allows the opening of inlet 1 towards the outlet 2. The ring "**D**" determines the value of the maximum stroke of the plunger.
As the activation of the plunger ceases, the air pressure in inlet 1 pushes the seal **C** upwards, at the same time as the plunger stem **A**. Inlet 1 is closed and the internal spring pushes the stem further upwards, so that by detaching itself from the seal, it reopens the passage between outlet 2 and exhaust port 3.

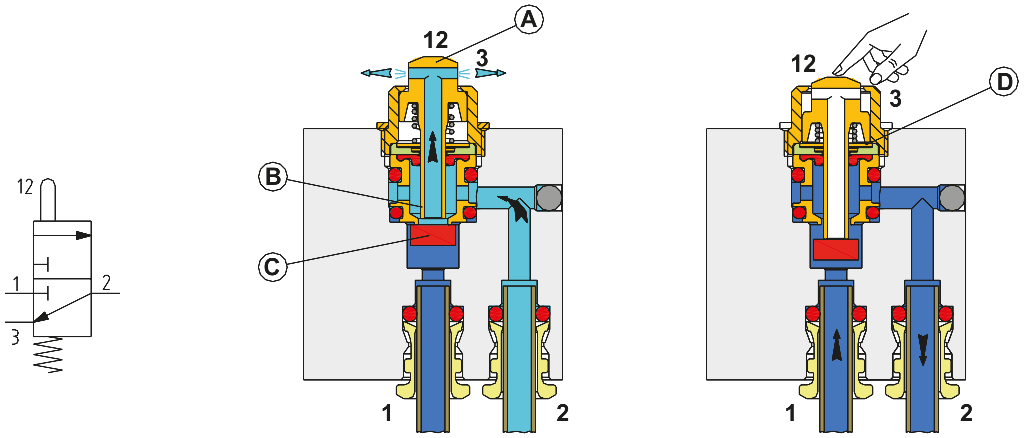


Fig. 14

Figure 15
Model: 3/2-way NO
The connections for inlet 1 and outlet 2 are positioned exactly as they are on the NC valve, the exhaust port 3 is located on the valve body and obtained through a side passage which is not threaded.
The compressed air from inlet 1 passes through the diaphragm **G** and the elevated plunger stem is able to go towards outlet 2. The seal **E** closes the passage to the exhaust 3.
The activation of the mini-valve is obtained by lowering the plunger stem with a small stroke. The passage from inlet 1 to outlet 2 closes through the membrane **G**, and, at the same time, the seal **E**, through its movement, opens the passage from the outlet 2 to the exhaust 3. Upon the release of the plunger stem, the internal spring re-assumes the initial position and through seal **E**, closes the passage from outlet 2 to exhaust 3. The diaphragm **G**, upon release, reopens the passage from inlet 1 to outlet 2.

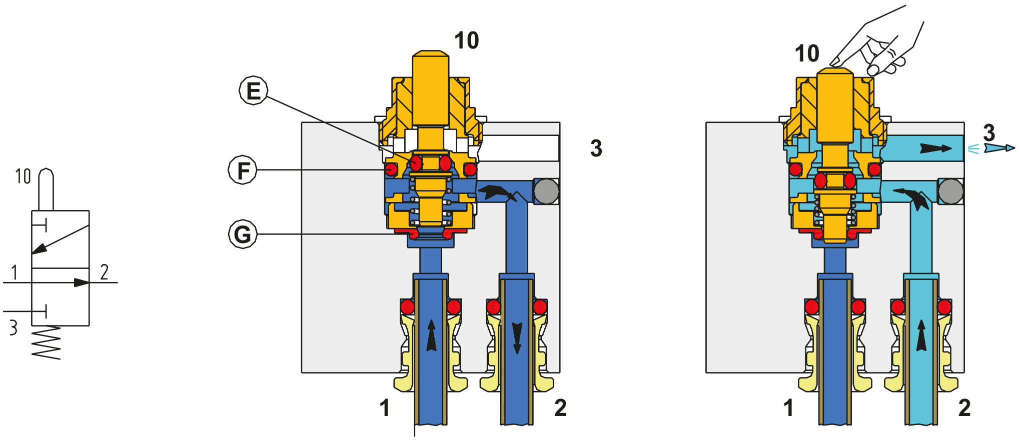


Fig. 15

3/2-way spool valves

The spool is a cylinder, typically metallic, with two different diameters, appropriately connected. By means of its axial movement inside the valve and due to the seals on the larger diameter, it connects the various passages through which the compressed air is channelled.

Figure 16

In this example, as illustrated in the drawing, there is no intermediate zone in which, during switching, all of the internal passages are closed. One channel always remains open:

- it is the passage from the inlet 1 to the outlet 2
- or the passage from the outlet 2 to the exhaust 3.

Another difference is that at an equal flow rate of compressed air, the spool must perform a longer stroke; this results in an increase in the response time and size (length of the valve).

The spool does have some advantages such as:

- it can function with any operating device
- the compressed air can be connected to any of the ports (inlet 1, outlet 2 and 4 and exhaust ports 3 and 5)
- the possibility to use any pressure value and even vacuum (the maximum values are given by the manufacturer).

Due to the flexibility of this type of valve, it is necessary to ensure that the operating device is supplied with the necessary force.

The internal elements of the spool valve are normally: spool, spacers and seals between spool and body. The spool, via the operating device, (which at present is not taken into consideration), moves along its axis inside the spacers and seals and allows the separation of the various ports/channels due to the interference created by its larger diameter being in contact with the seals..

This type of valve may be used when the movement of the spool is operated mechanically or manually, it can be used in NC Pos. **A** mode and in NO Pos. **B** mode merely by reversing the inlet and exhaust port connections.

In these valves the pressure of the compressed air acts evenly on the entire surface of the spool, while in poppet valves, the pressure of the compressed air tries to raise the sealing element, for this reason the spool valves are defined as "balanced".

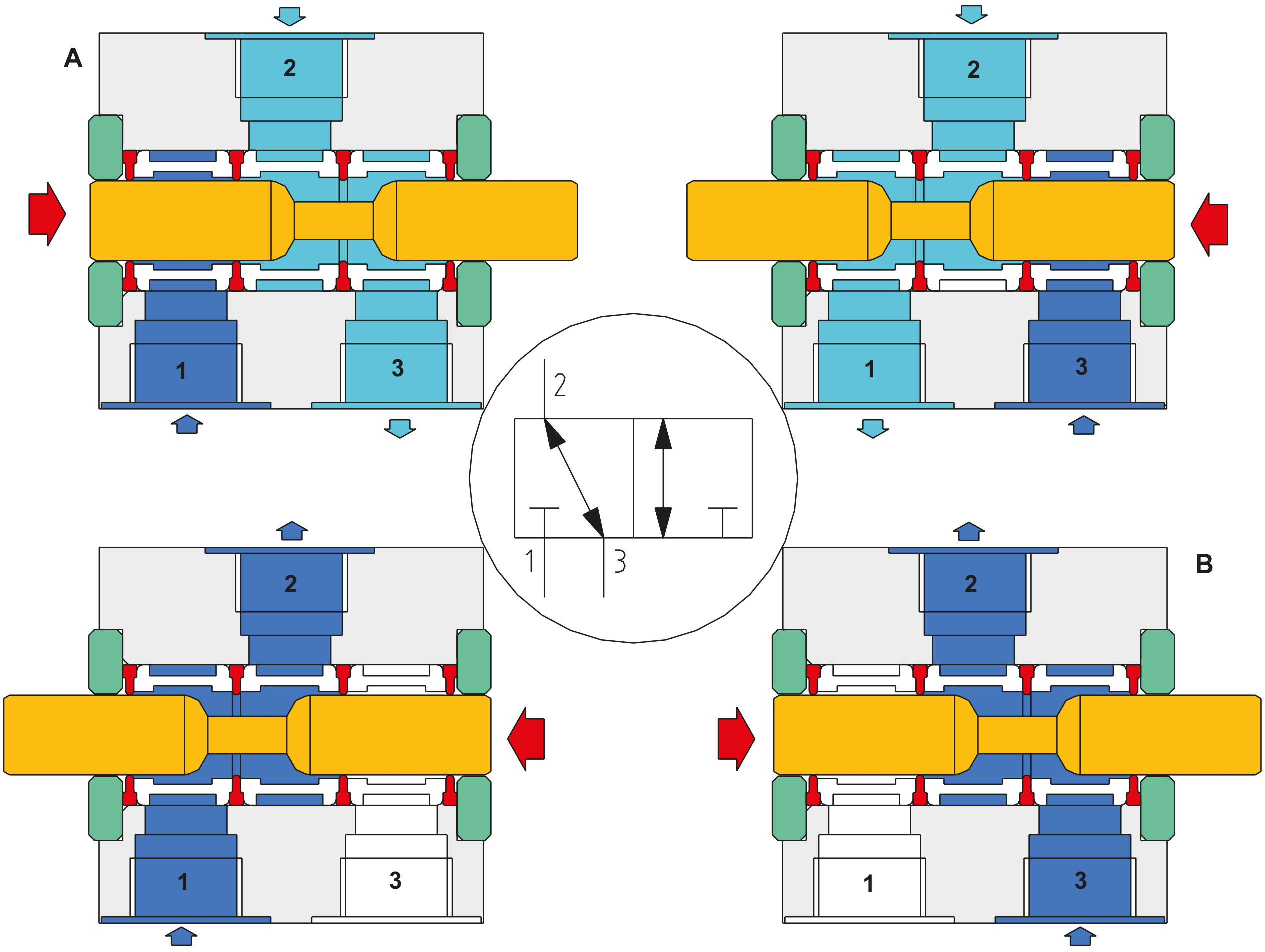


Fig. 16

5/2-way spool valves

In 3/2-way valves, compressed air is directed towards the only outlet, identified by the numerical value 2. In the 5/2-way valves there are two outlets represented by the numbers, 2 and 4 respectively, with corresponding exhaust ports 3 and 5.

- The supply pressure is always indicated by the number 1
- The outlet is indicated by the number 2 and its exhaust by the number 3
- The outlet is indicated by the number 4 and its exhaust by the number 5.

There are 5 ways while the positions are still 2. Having a greater number of passages, the spool has a different structure with a greater amount of spacers and seals, and is consequently larger (longer) than a 3/2-way valve. In 5/2-way valves, NC or NO versions do not exist because the inlet 1 is always connected to one of the two outlets 2 or 4.

Figure 17
Pos. A:
the spool is moved fully to the left as a result of the pilot signal 12,
inlet 1 is connected to outlet 2,
while exhaust port 3 is closed,
outlet 4 is connected to exhaust 5.
Pos. B:
the spool has moved completely to the right as a result of the pilot signal 14,
inlet 1 is connected to outlet 4,
while exhaust 5 is closed,
outlet 2 is connected with exhaust 3.

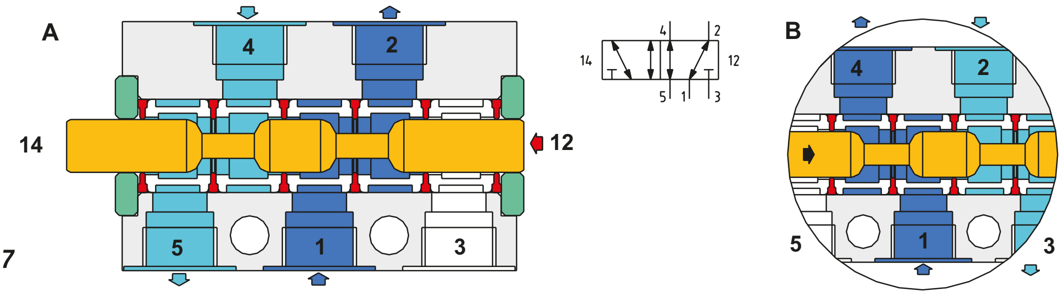


Fig. 17

As previously mentioned, spool valves also allow for the use of different connections to the compressed air inlet. Operation of the 5/2-way valve with different supply pressure from exhausts ports 3 and 5.

Figure 18
Pos. C:
the spool is moved completely to the left as a result of the pilot signal 12,
the supply pressure from 5 is in connection with outlet 4,
while 2 is exhausted through port 1,
the outlet pressure supply on port 3 is closed.
Pos. D:
the spool has moved completely to the right as a result of the pilot signal 14,
the supply pressure from 3 is in connection with outlet 2,
while 4 is exhausted through port 1,
the outlet pressure supply from port 5 is closed.

Use of a 5/2-way valve as a 3/2-way valve.
Pos. E: to obtain this function, you only need to close one of the two outlets 2 or 4 with a plug, the corresponding exhaust may remain unused. The connection which is not used is indicated symbolically by a horizontal line. The 5/2 valve is normally used to control a double acting cylinder, where the movement of the piston is obtained by alternately introducing compressed air in a chamber while exhausting the opposite chamber.

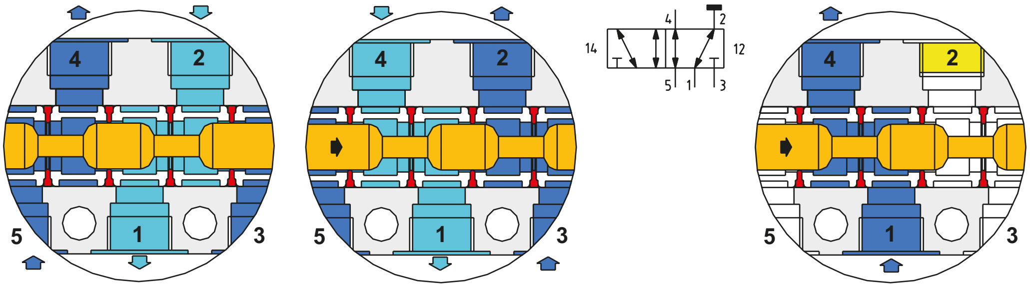


Fig. 18

Manual and mechanical operating devices for spool valves

To change the position of a valve it is necessary for the valve to receive a command. This command can be mechanical, manual, electric or pneumatic. Manual control is defined as a command given by the action of an operator.
Mechanical control is defined as a command determined through the movement of a mechanical nature.
To provide a specific command an "actuation device" is installed on the valve to execute one of the commands listed above.

Monostable operation devices
The function of the manual operating devices of pneumatic valves is similar to the function of electric devices, e.g. mushroom pushbuttons, encapsulated pushbuttons, horizontal levers, rotary switches etc.

Figure 19
Pos. A: symbol of a manual lever.
Pos. B: symbol of a push button.
Some examples of mechanical actuation devices:
Pos. C: symbol of a mechanical (frontal) pin.
Pos. D: symbol of a roller lever.
Pos. E: symbol of a unidirectional roller lever.

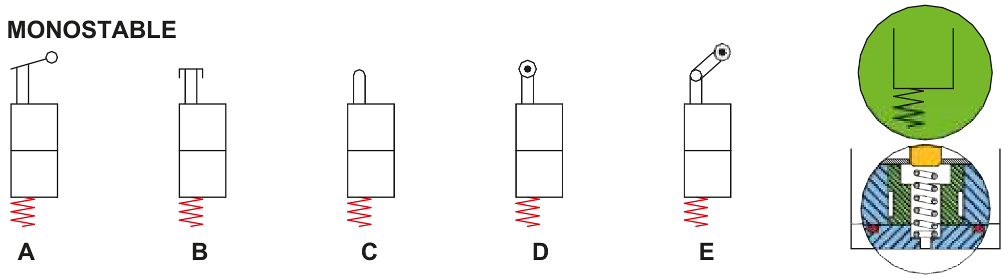


Fig. 19

The type of actuation is graphically depicted in the upper zone of the square, indicating that its function is a valve. The operating device is repositioned due to the action of an internal spring once the manual/mechanical actuation is interrupted. The valve has its own system of repositioning, the device is specified in the lower section of the square which indicates the valve function; generally, it is a mechanical or pneumatic spring.

Bistable operation devices
In some cases the position determined by the initial command must also be maintained once the command is interrupted. In these cases, the starting position is obtained via a second command, which is opposite to the previous command. Also in this case, the position determined by the initial command is maintained once the command is interrupted. The following are various types of bistable manual actuation devices; selector, button with restraint (such as an emergency pushbutton) for example;

Figure 20
Pos. F: symbol of a manual push and pull operation.
Pos. G: symbol of a selector lever.
Some examples of mechanical operating device:
Pos. H: symbol of a (frontal) pin on both sides.
Pos. I: symbol of a roller lever on both sides.
Pos. M: symbol of a unidirectional roller lever from both sides.
There are also mechanically actuated valves with external pneumatic return:
Pos. N: symbol of a roller lever and external pneumatic return.
Pos. O: symbol of a unidirectional roller lever and external pneumatic return.
Pos. P: a symbol of a (frontal) pin and external pneumatic return.

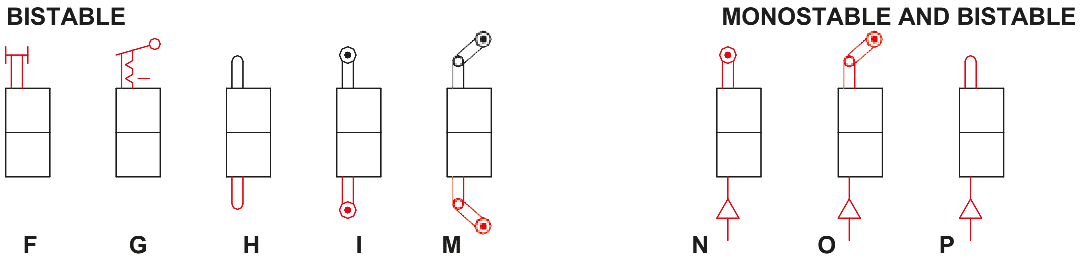


Fig. 20

Pneumatic operating devices for the valves

The operating devices are categorised as;

direct control valves i.e. the force applied, whether manual or mechanical acts directly on the spool or poppet of the valve.
indirect: the compressed air moves the internal part of the valve.

When using pneumatically operated valves, the pilot signal is indirect, in the sense that, the pilot signal is provided by an external element that opens/closes a passage of compressed air.
The pilot air acts on a piston inside the valve, in the case of bistable valves, the thrust force generated by this piston must be sufficient to move the spool whereby overcoming the internal friction. On monostable valves, the thrust force must be sufficient to overcome both friction and the resistance of the return device, therefore the monostable valves require a pilot pressure greater than necessary for bistable valves.

Figure 21
Pneumatic actuation of a monostable valve with spring return.
Pos. A1: in the absence of a pilot signal the spring keeps the spool at rest position.
Pos. A2: in the presence of a pneumatic pilot signal, the piston on the left moves to the right, the small piston pushes against the spool, overcoming the force of the return spring thereby compressing the spring. The valve activates and remains in this position for as long as the pilot signal is present.
Pos. A3: when the pilot signal is removed, the spring reacts and returns the spool to its initial position.
Pneumatic actuation of a bistable valve.
Pos. B1: in this version there are two pistons of equal surface area positioned at each end of the spool. In the absence of a pilot signal, the spool will remain located in the position defined by the last received signal.
Pos. B2: in the presence of a pilot signal on the left side, the piston moves to the right, pushing the spool and the piston to the right. The valve has switched.
Pos. B3: when the pilot signal is removed, the valve remains in this position.
Pos. B4: in the presence of a pilot signal on the right side (and in the absence of the pilot signal on the left) the piston moves to the left, pushing the spool and the piston to the left. The valve has switched.
Pos. B5: the simultaneous presence of two pilot signals does not change the position of the spool.
Pneumatic actuation of a valve with preferential repositioning (dominant).
Pos. C1: in this version you have two pistons with different sizes on the pilot valve. In the absence of the pilot signal, the spool is located in the position defined by the last received signal.
Pos. C2: in the presence of a pilot signal on the left side, the piston moves to the right, pushing the spool and the piston to the right. The valve has switched.
Pos. C3: when the pilot signal is removed, the valve remains in its pre-determined position.
Pos. C4: in the presence of a pilot signal on the right (and in the absence of the pilot signal on the left) the piston moves to the left, pushing the spool and the piston to the left. The valve has switched.
Pos. C5: the simultaneous presence of the two pilot signals changes the position of the spool. The spool moves to the right (in the direction of where the piston is smaller). The reason is that the thrust force of the larger piston is greater than the thrust force of the smaller and therefore the larger becomes the dominant piston.

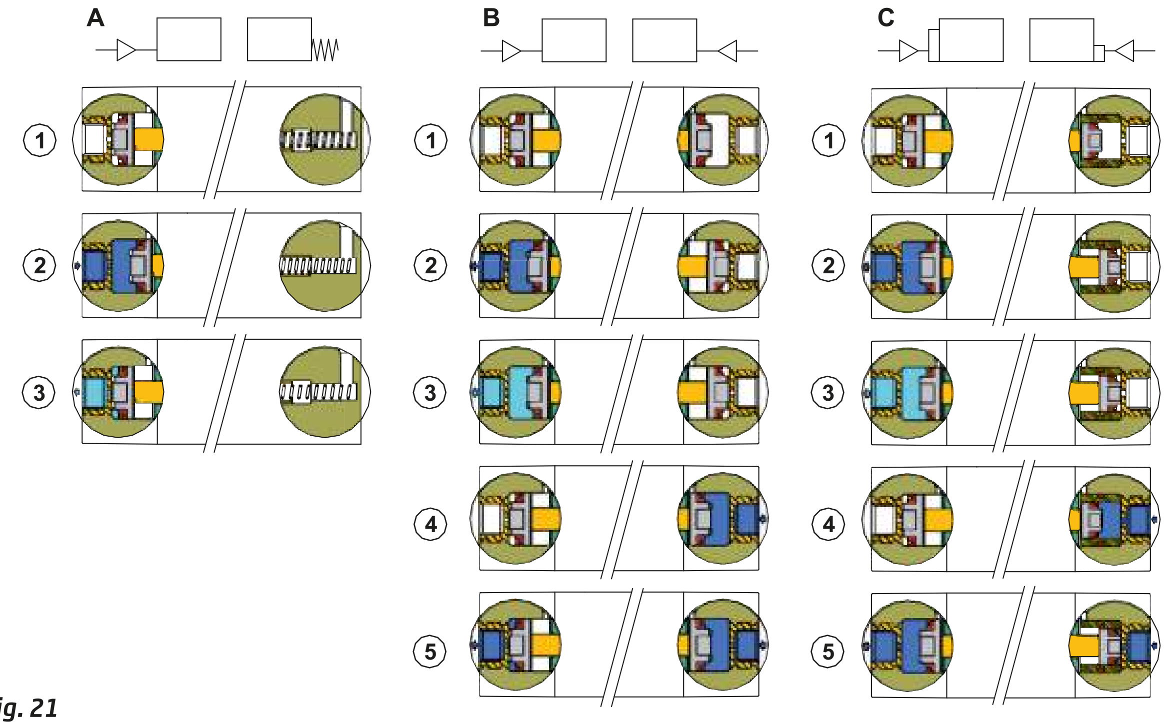


Fig. 21

Directly operated solenoid valves

In addition to the systems discussed above, the valves can also be charged over electrical signals, however, these electrical signals must be converted into a pneumatic pilot signal. This operation is performed by the **solenoid pilot valve**, which consists of the solenoid, electronics and mechanical components, a fixed plunger and the mobile plunger.

Figure 22
Pos. 1: **the solenoid (coil)**
The solenoid is formed by a winding of copper wire **A**, around a bobbin **B** protected by a metallic armature **C**. It is often encapsulated in an isolating material which defines the shape and external dimensions. Electrical connection is provided by two or three pins protruding from the solenoid. The arrangement of these pins determines the shape and adheres to various standards such as DIN 43650 and DIN 40050. The solenoid, being an electrical component, must be used in accordance with certain criteria, the main being:
Temperature: being a parameter that can vary considerably depending on where the solenoid is operating, manufacturers will specify the minimum and maximum compatible temperatures.
Humidity: depending on the characteristics of the material used for over-molding, the solenoids can be suitable for different applications.
Value of the current: this depends on the electric power of the solenoid. The modern solenoids generally need low power in order to reduce consumption, heating and size. When operating with direct current (DC), they require the same current during the acceleration phase as well as during the holding phase. While operating with alternating current (AC), they require a higher current value during the acceleration phase than during the holding phase. Providing an alternating current to the solenoid without the internal mechanical part inside can cause damage. It is important to disconnect the power supply or remove the connector from the solenoid before removing the solenoid from the valve.
Duration of the electrical signal: the solenoids are designed to provide the same performance level with constant supply of electricity; this indication is normally identified with ED 100%. In recent years different techniques, such as the PWM (Pulse Width Modulation) technology have become widespread.
Working environment: all solenoids produce heat when supplied with an electric current. Installation in closed control panels is to be avoided when deprived of adequate ventilation, or in hot environments with inadequate heat dissipation, especially for groups of valves where the solenoids are mounted within close proximity.
Pos. 2: **Fixed plunger and mobile plunger**
The fixed plunger **E** is rigidly mounted on the plunger tube **D**, made with non-magnetic material, stainless steel or brass. The solenoid is fitted on the plunger tube.
The fixed plunger **E** has several functions: it contains the copper ring **G**, called the “phase shifting ring”, which serves to reduce the vibrations produced by the magnetic field when using a power supply with an alternating current. The central part of the fixed plunger can have an air passage which can be sealed off, (however this topic will be approached later). It also limits the stroke of the mobile plunger and allows for the closing of the solenoid.
The mobile plunger **F** has several functions: by providing voltage to the solenoid, it generates the magnetic field, which pulls the mobile plunger upwards, elevating it to be in contact with the fixed plunger **E**. The red-colored seal in the upper section closes the orifice of the fixed plunger. The cylindrical internal spring **I** exerts a thrust force on this seal ensuring the closure of the orifice. The lower seal, by rising together with the mobile plunger, determines the opening or closing of the passage of compressed air (C/A), (this will also be analyzed later).
Removing the voltage, the magnetic field ceases, the spring **H** repositions the mobile plunger. The two grooves on the mobile plunger enable the air to reach the exhaust channel of the fixed plunger.

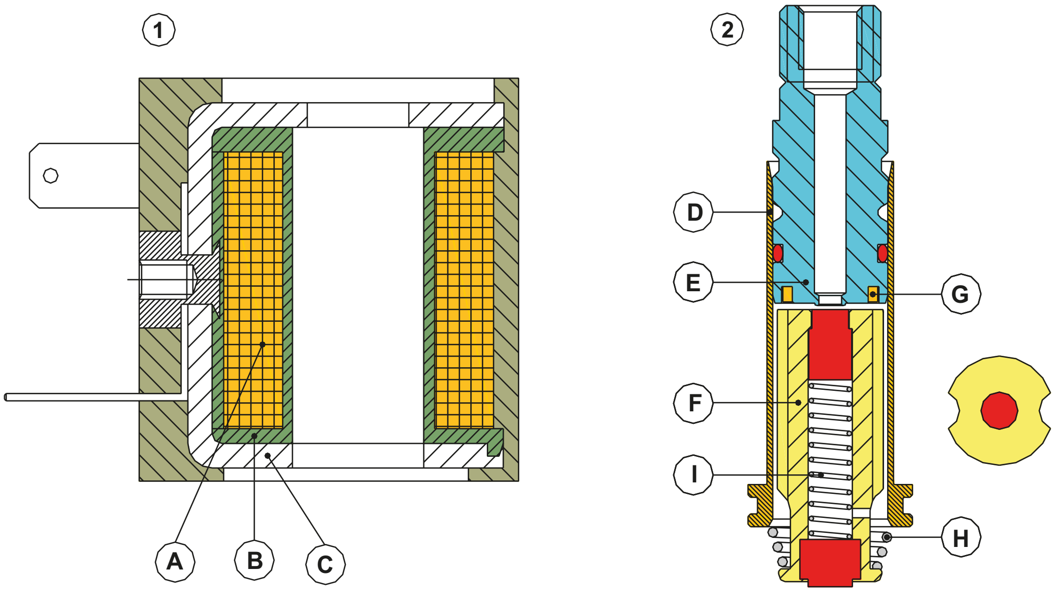


Fig. 22

3/2-way NC solenoid valve (3-way, 2-position, normally closed)

Figure 23
Rest position, electrical contact open, absence of electrical energy.
Pos. A: the conical spring pushes the mobile plunger and its seal against the orifice, closing the passage of C/A from inlet 1 towards outlet 2.
Pos. B: under the action of the conical spring, the upper part of the mobile plunger and its seal, are detached from the fixed plunger, putting outlet 2 in communication with the exhaust 3.

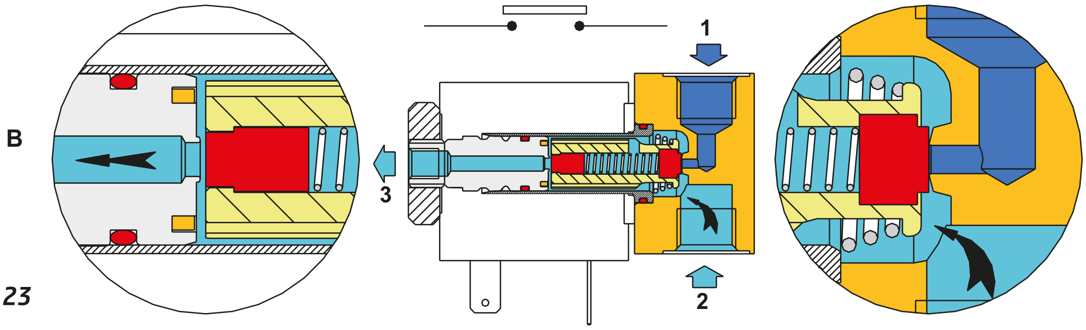


Fig. 23

Figure 24
The electrical contact is closed, there is passage of electrical energy, voltage is supplied to the solenoid.
Pos. C: a current flows through the solenoid generating a magnetic field that attracts the mobile plunger upwards. The conical spring compresses and the seal is detached from the orifice. It opens the passage of C/A from inlet 1 to outlet 2.
Pos. D: the surface of the upper part of the mobile plunger is in contact with the lower surface of the fixed plunger, the seal closes the passage towards the exhaust 3.

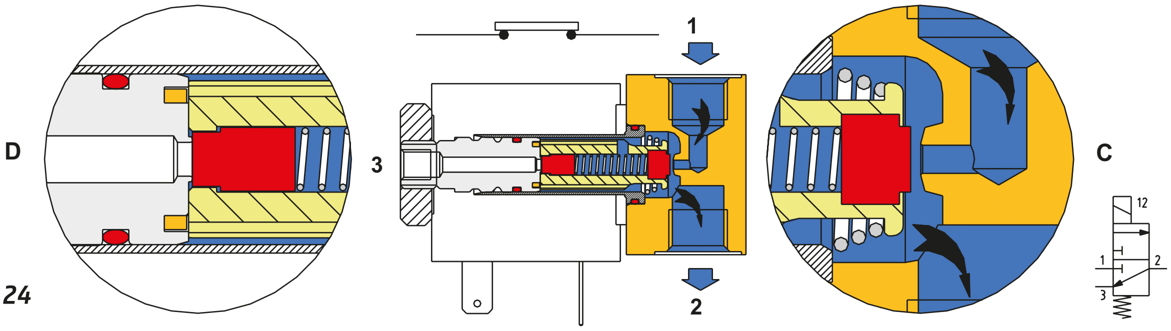


Fig. 24

3/2-way NO solenoid valve (3-way, 2-position, Normally Open)

In comparison with the 3/2-way NC solenoid valve we observe the following differences:
- the location of inlet 1 and exhaust 3;
- the load of the internal springs.

Figure 25
Rest position, electrical contact open, absence of electrical energy.
Pos. A: the conical spring pushes the mobile plunger and its seal against the orifice closing the passage of C/A from inlet 1 to exhaust 3.
Pos. B: under the influence of the conical spring, the upper section of the mobile plunger and its seal, are detached from the fixed plunger, putting inlet 1 in communication with outlet 2.

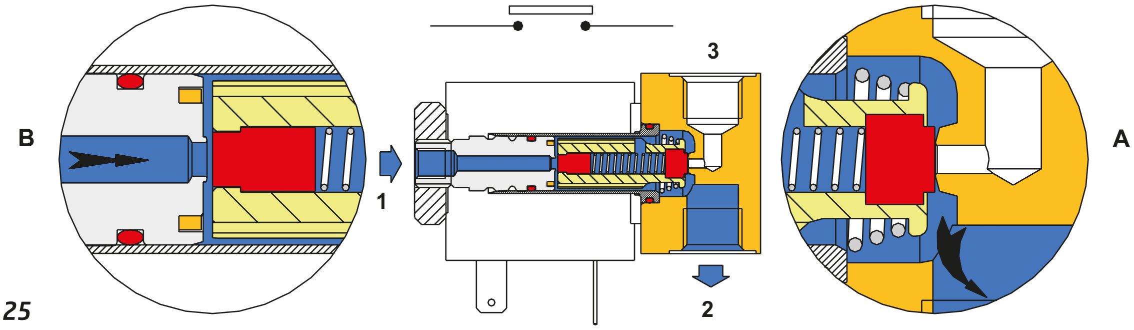


Fig. 25

Figure 26
The electrical contact is closed, there is passage of electrical energy, and voltage is supplied to the solenoid.
Pos. C: a current flows through the solenoid generating a magnetic field that pulls the mobile plunger upwards. The conical spring compresses and the seal is detached from the orifice. It opens the passage of compressed air from outlet 2 to exhaust 3.
Pos. D: the surface of the upper part of the mobile plunger is in contact with the lower surface of the fixed plunger, the seal closes inlet 1 of the compressed air.

In this version the load of the conical spring is smaller than that of the NC solenoid valve, as it must not overcome the thrust of the C/A which attempts to raise the mobile plunger. The reduced load of the conical spring offers a smaller resistance to the lifting of the mobile plunger triggered by the magnetic field.

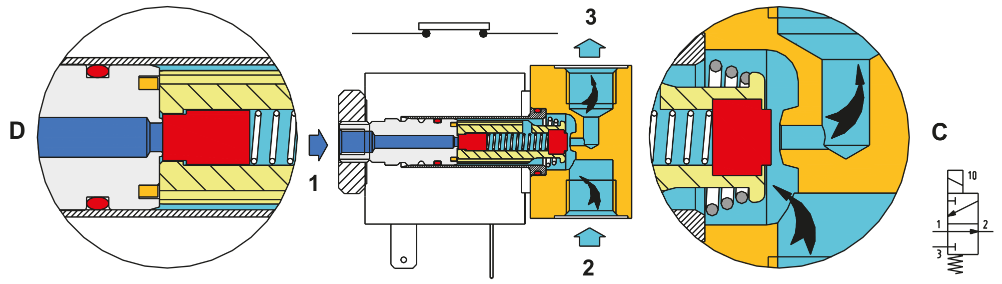


Fig. 26

3/2-way NO solenoid valve (3-way, 2-position, Normally Open, in-line mounting)

Inside the plunger tube construction we find three basic components:
- the mobile plunger
- the fixed plunger
- the lower seal support.

Figure 27
Pos. 1: rest position, open switch, absence of electrical energy.
A: the spring, located outside the lower seal support, raises this support, enabling the air passage from inlet 1 to outlet 2. This support has an extension in the shape of a rod, drilled in the central upper section, which through the fixed plunger initiates contact with the mobile plunger.
B: the mobile plunger, unaffected by the magnetic field, and due to the thrust of the lower seal support (described above), is raised. The seal of the mobile plunger that has been raised closes the orifice of the exhaust 3.
Pos. 2: the electrical contact is closed and there is passage of electrical energy, and voltage is supplied to the solenoid.
C: the current flows through the solenoid generating a magnetic field, which depresses the mobile plunger and consequently the lower seal support. This compresses the spring and the seal comes into contact with the lower orifice, closing the inlet 1.
D: the mobile plunger is lowered by the effect of the magnetic field, and in addition to allowing the closure of inlet 1, it detaches the upper seal from the exhaust orifice allowing the passage from the outlet 2 to the exhaust 3.
E: section of the mobile plunger with the highlighted (red) upper seal and the milled groove, which allows the passage of the compressed air.
The pneumatic symbol is completed with a small square, which represents electrical pilot signal 10.
The command "10" indicates that in the presence of this signal, inlet 1 is closed.

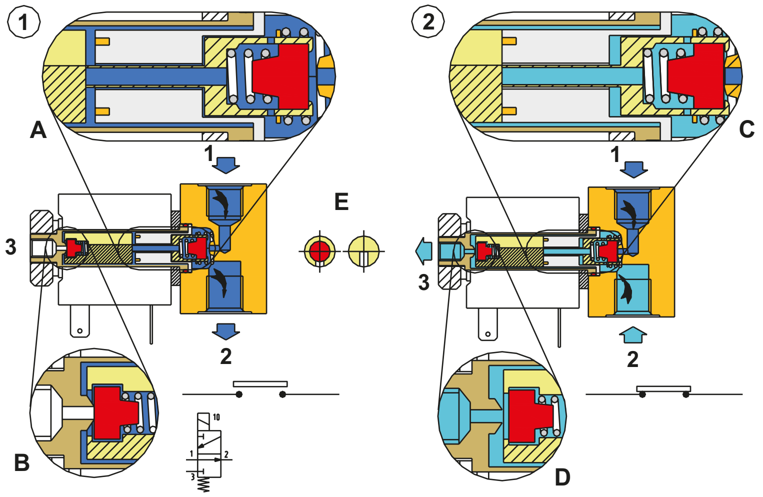


Fig. 27

The 2/2-way NO or NC valves are generally used in applications that involve blowing operations, or tank filling, closing a flow, etc. Aesthetically they do not present any substantial differences to the 3/2-way valves apart from the absence of connection of the exhaust 3 and the different connection points.

2/2-way NO solenoid valve (2-way, 2-position, Normally Open)

Figure 28
Rest position, electrical contact open, absence of electrical energy.
Pos. A: to reduce the number of components, the body of the 3/2-way version is typically used; however the port that would have been closed is plugged. The conical spring pushes the mobile plunger and its seal against the orifice connected to the plugged port.
Pos. B: under the influence of the conical spring, the upper part of the mobile plunger and its seal are detached from the fixed plunger and its orifice, which enables the connection between inlet 1 and outlet 2.

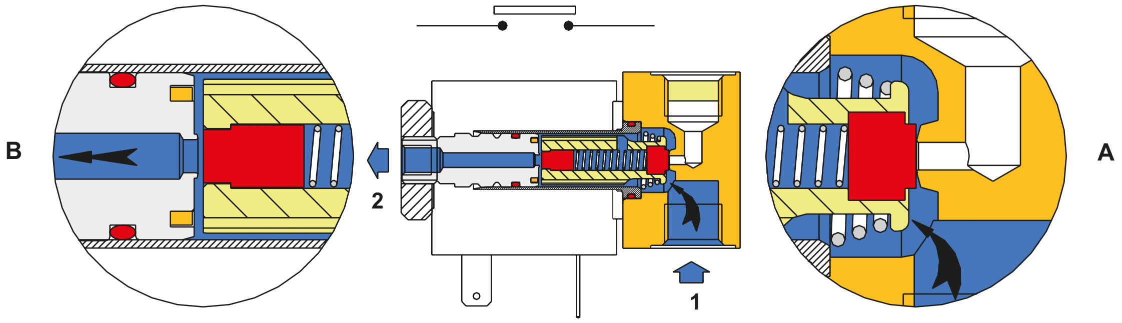


Fig. 28

Figure 29
The electrical contact is closed, there is passage of electrical energy, voltage is supplied to the solenoid.
Pos. C: a current flows through the solenoid generating a magnetic field that attracts the mobile plunger upwards. The conical spring compresses and the seal is detached from the orifice.
Pos. D: the surface of the upper part of the mobile plunger is now in contact with the lower surface of the fixed plunger, the seal closes the passage between inlet 1 and outlet 2.

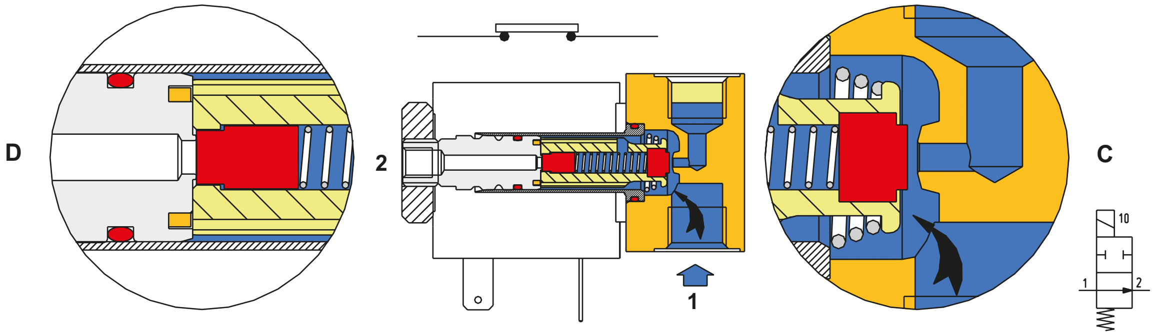


Fig. 29

Regardless of the type of actuation, the operation of the poppet valve depends on the pressure and the size of the orifice under the poppet on the inlet side. The mobile plunger, previously analyzed, represents the poppet, which via a seal and a conical spring keeps the orifice closed. In this state, the conical spring is dimensioned in such a way that it overcomes the thrust that the pressure of the compressed air generates on the surface of the plunger in contact with the orifice. As the pulling force of the solenoid that moves the mobile plunger "is considered to be constant", there is a proportional relationship between pressure and diameter of the orifice. With high pressure the diameter of the orifice will have to be smaller, with low pressure the diameter may be larger.

The 2/2-way NC valves are typically used for blowing operations such as taps where it's necessary for the passage areas to have greater diameters and high pressure. These requirements are achieved due to a different construction, the seal of the mobile plunger and different flow directions of the compressed air.

2/2-way NC solenoid valve (2-way, 2-position, normally closed)

Figure 30
Rest position, electrical contact open, absence of electrical energy.
Pos. A: the incoming compressed air does not act on all the surfaces of the mobile plunger, but only on the inner part of the orifice where the plunger closes the passage towards the outlet 2. The thrust of the air favors closing, in preference to opening. By limiting the maximum working pressure one can increase the diameter of passage towards outlet 2 while keeping the same solenoid. With this solution there are no anomalies even in the presence of strong pressure oscillations, as in the case of bursts of air.
Pos. B: the force exerted on the mobile plunger is greater on the spring side as apart from the force of the spring, the forces on the surfaces of the upper and lower end of the plunger affected by the pressure are different. The presence of pressure to outlet 2 favors the elevation of the mobile plunger, in the absence of pressure, greater power for the actuation is required.

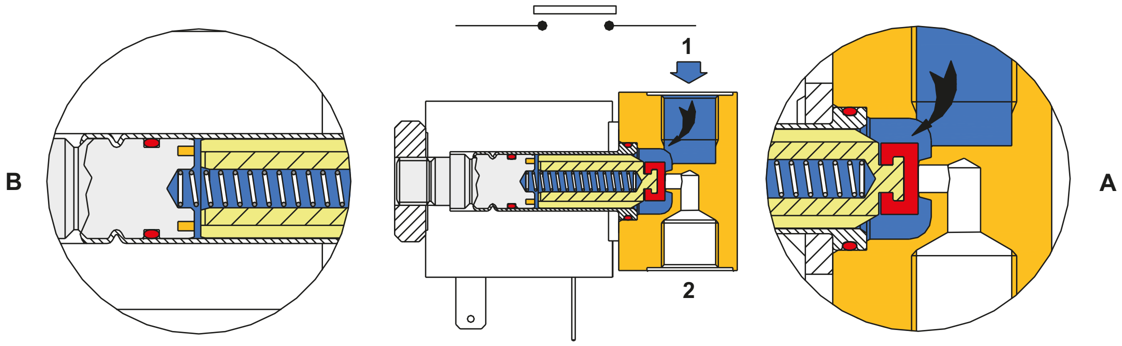


Fig. 30

Figure 31
The electrical contact is closed, there is passage of electrical energy, and voltage is supplied to the solenoid.
Pos. C: a current flows through the solenoid generating a magnetic field, which pulls the mobile plunger upwards. The internal conical spring compresses and the seal is detached from the orifice. It opens the passage of C/A from inlet 1 outlet 2.
Pos. D: the surface of the upper section of the mobile plunger is in contact with the lower surface of the fixed plunger.

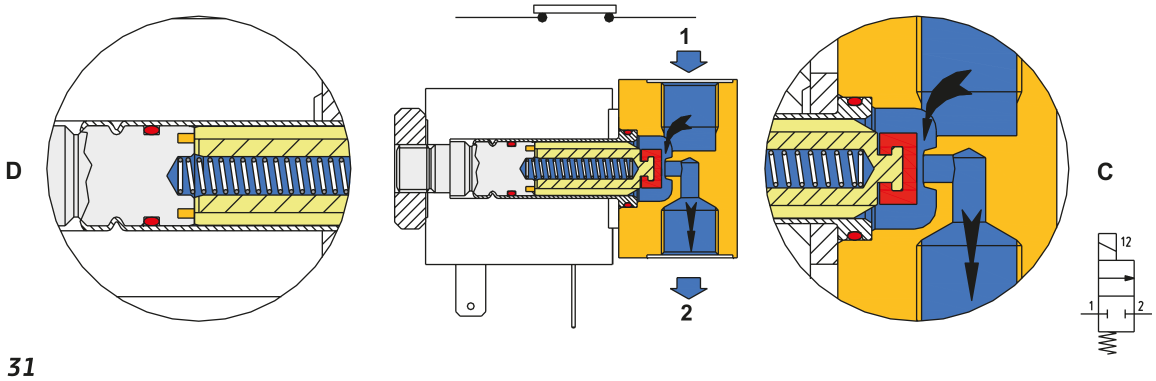


Fig. 31

Solenoid valves with internal servo pilot

As a result of demand from the market for components with reduced dimensions and low power consumption, the solenoid valves must be equipped with the smallest possible solenoids with reduced power consumption. In these cases, the solenoid is not acting directly on the switching, but on opening or closing the power supply to the control piston as analyzed in the **"Types of pneumatic activation in valves"**.
The solenoid group can vary in shape, type of electrical connection or regulations, and matches the end covers that contain the previously mentioned control piston. The air supply to the solenoid is the same as that supplied to the main valve and is obtained via an internal channel inside the valve. This feature defines the valve as the **servo valve with internal pilot**.

Figure 32
Solenoid valve with dual electric command

The central body is that of a normal spool valve in which there is internal channeling of the servo-pilot. The ends of the body are closed by end covers that integrate the solenoids. The main air supply from inlet 1 also powers the solenoids, their respective output drives the pilot pistons.
The solenoid on the right is energized; the outgoing air moves the pilot piston which moves the spool to the left. In this phase, the solenoid on the left should not be energized. When removing the electrical signal to the solenoid, the solenoid valve holds the position. This solenoid valve is called Bistable with internal servo pilot.

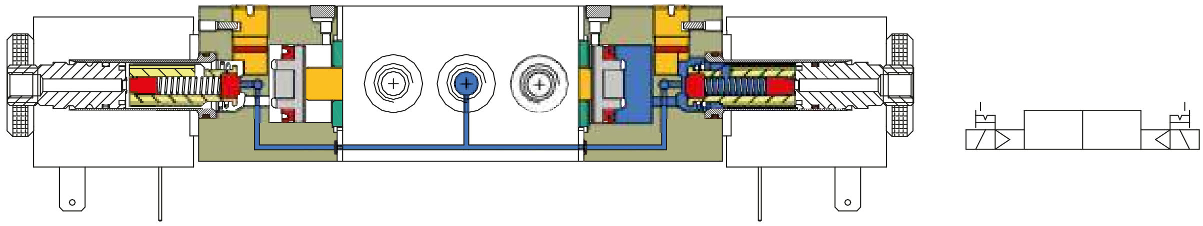


Fig. 32

Figure 33
Solenoid valve with electric command and spring return (monostable valve)

In this situation, the solenoid to the right has been replaced by a mechanical spring. The solenoid on the left is energized, the pilot air moves the pilot piston, which moves the spool to the right, and compresses the return spring. When releasing the electrical signal from the solenoid, the solenoid valve returns to its rest position due to the thrust of the spring. With the solenoid no longer energized, the solenoid valve assumes the position defined by the spring. This solenoid valve is called a Monostable valve with mechanical spring return and internal servo pilot.

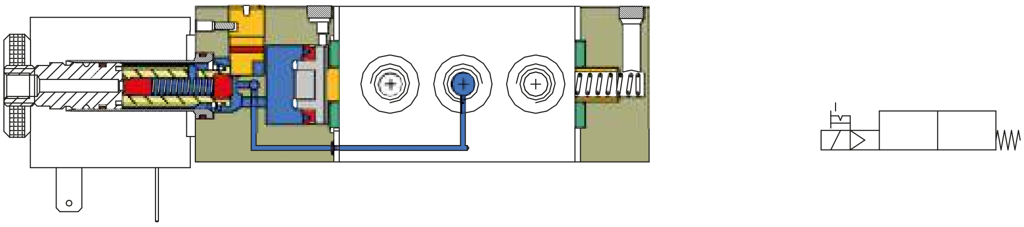


Fig. 33

Figure 34
Solenoid valve with electric command and pneumatic spring return

Unlike the previous case a pneumatic rather than mechanical spring is used. The pneumatic spring is made by a piston, still pressurized, but smaller than the spring on the end cap with the solenoid.
When the solenoid is not energized and in the presence of compressed air, the solenoid valve assumes the position determined by the pneumatic spring. This solenoid valve is called a Monostable valve with pneumatic spring return and internal servo pilot.

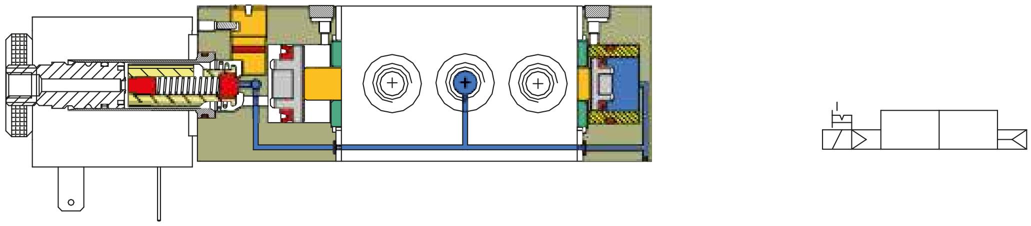


Fig. 34

Figure 35
Solenoid valve with electric command and pneumatic return
The end cap to the right, commonly called "pneumatic end cap", has a threaded port to which an external pilot can be connected. The two control pistons have the same diameter. The repositioning of the spool takes place only in the presence of external pneumatic piloting. When removing the electrical signal from the solenoid, the valve position does not change, it does so only in the presence of an external pilot. In this condition it is called a Bistable with electric command with external pneumatic repositioning.
In the situation where the external pneumatic command is always present though with reduced pressure, the valve would be Monostable with electric command with pneumatic repositioning spring.

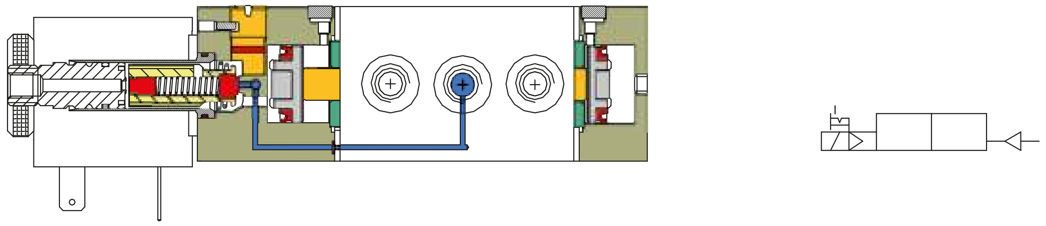


Fig. 35

Solenoid valves with external servo pilot

As shown in indirect command valves this is a solenoid valve, which provides control to the pilot (signal) by opening or closing a passage of compressed air.
The pneumatic supply to the solenoid is the same as that supplied to the main solenoid valve and is obtained via an internal channel to the valve. Depending on the type of solenoid valve the minimum pressure required for piloting control is approx. 2 bar. In situations where a low pressure or vacuum is used, it is necessary to supply the solenoid valve with a different pilot pressure. In this situation, the solenoid valves that have a separate connection for the power supply are used and are defined as **with external servo pilot**.

There are no particular differences between the two types.

Figure 36
Solenoid valve with dual electric command and external servo pilot
The central body is that of a normal valve where the channeling of the servo-pilot is absent or intercepted. Each end of the body is closed by an end cover which has the function of a pilot valve. The air supply of the main valve is independent from that of the pilot valve, the output of air drives their respective pilot pistons. The solenoid on the right is energized; the outgoing pilot air moves the pilot piston, which moves the spool to the left. In this phase, the solenoid valve on the left should not be energized. When removing the electrical signal to the solenoid, the valve holds the position. This solenoid valve is called Bistable with external servo pilot.

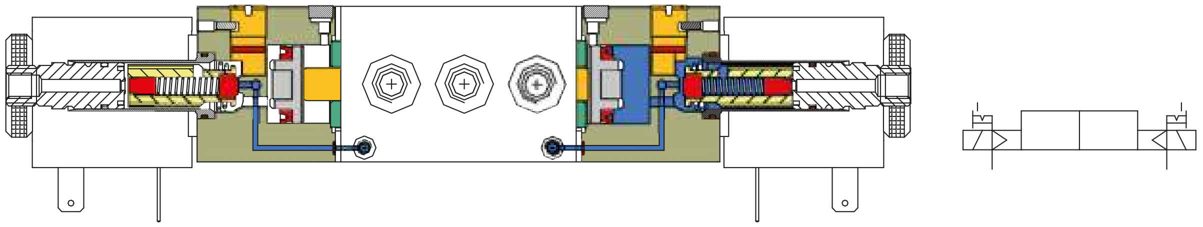


Fig. 36

Figure 37
Solenoid valve with electric command, mechanical spring return and external servo pilot
In this case, the solenoid on the right has been replaced by a mechanical spring. The solenoid on the left is energized, the outgoing air moves the pilot piston, which moves the spool to the right, the return spring compresses. When releasing the electrical signal to the solenoid, the solenoid valve returns to its rest position due to the effect of the spring. When the solenoid is not energized, the solenoid valve assumes the position defined by the spring. This solenoid valve is called Monostable with mechanical spring return and external servo pilot.

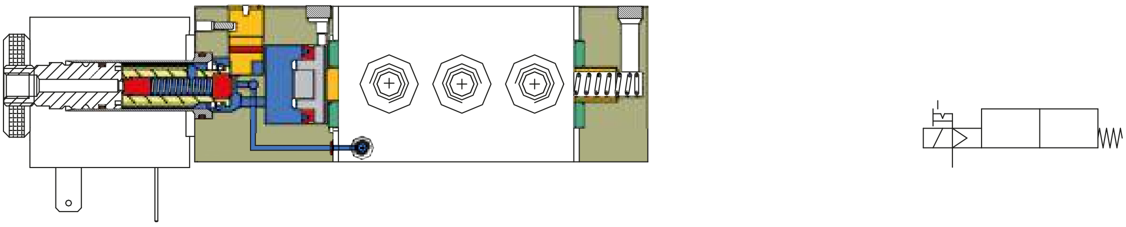


Fig. 37

Figure 38
Solenoid valve with electric command, pneumatic spring return and external pilot air

In contrast to the previous situation, there is a pneumatic spring instead of a mechanical spring. The pneumatic spring is comprised of a small piston, powered by an external source, but with smaller dimensions than the piston on the end cap with the solenoid. In the situation where the solenoid is not energized, and there is compressed air, the solenoid valve assumes the position determined by the pneumatic spring. This solenoid valve is called Monostable with external pneumatic spring return and external servo pilot.

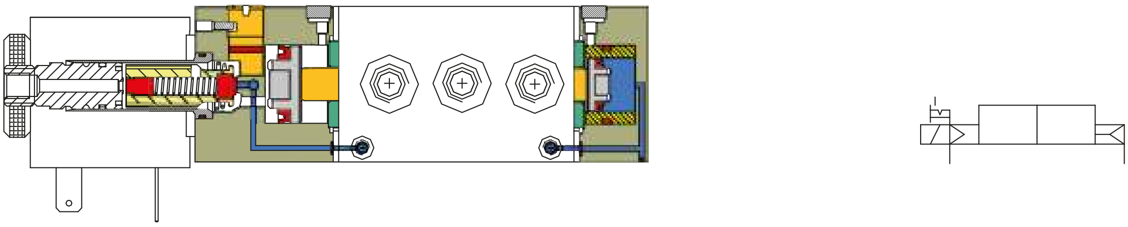


Fig. 38

Figure 39
Solenoid valve with electric command, pneumatic return and external servo pilot

The end cover on the right, commonly called "pneumatic end cover", has a threaded port to which an external pilot can be connected. The two pilot pistons have the same diameter. The repositioning of the spool occurs only in the presence of external pneumatic piloting. As the electrical signal ceases, the valve position does not change, it does so only in the presence of an external pilot signal. This solenoid valve is called Bistable with electric command, pneumatic return and external servo pilot. If the pneumatic return signal were to be always present but with reduced pressure, the valve would be Monostable with an electric command, pneumatic spring return and external servo pilot.

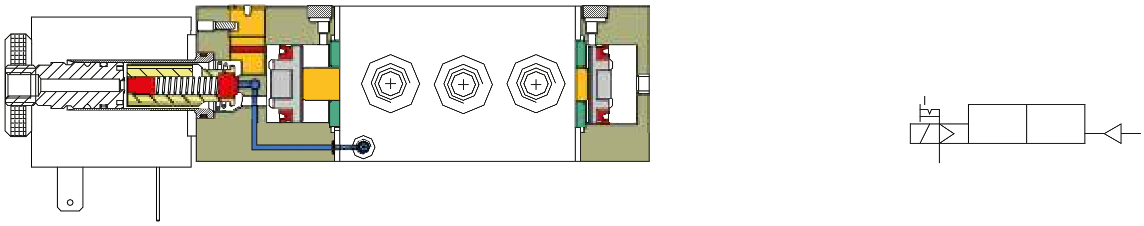


Fig. 39

Three-position valves

In these electrically or pneumatically operated valves, the third position is obtained through a repositioning spring which ensures the return of the spool to the center position in the absence of a pilot signal. The manually operated valves offer two distinct solutions:

- **Monostable valve**: releasing the control lever in either direction, the spool is repositioned to the center due to the action of the spring;
- **Bistable valve**: all positions are stable, in this case the central condition is obtained manually by acting on the lever.

The repositioning device may be realized in different ways, with separate springs in the two end caps or all on the same side. The third position of these valves can possess different versions:

Figure 40

5/3 CC - Closed centers: inlet 1 closed, outlets 2 and 4 are closed, and exhaust 3 and 5 are also closed.
The central position (third position) ensures that all connections are closed, preventing air discharge and supply to the cylinder. This type of valve is used to allow intermediate positions in cylinders. Not to be considered as a safety- or precision component.

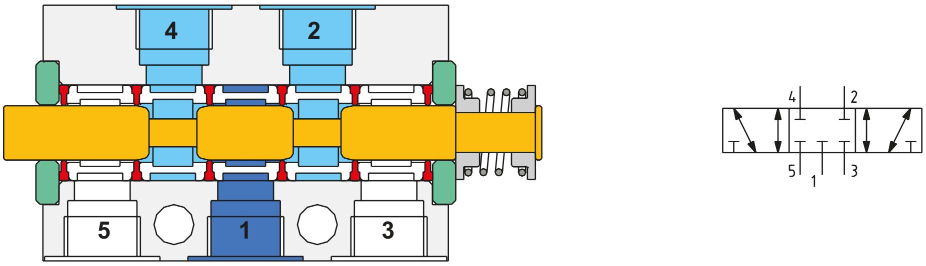


Fig. 40

Figure 41

5/3 OC - Open centers: inlet 1 is closed, outlets 2 and 4 are in communication with the exhaust ports 3 and 5.
The central position (third position) ensures that input 1 is closed while outlets 2 and 4 are in connection with their respective exhausts 3 and 5; this allows the exhaust of the cylinder chambers. This type of valve is used when it is necessary to move the cylinder externally/from the outside once it has stopped. With this type of valve, as the cylinder is in "neutral", it would be possible to manually move the piston rod back and forth, likewise any incorrectly positioned external object would also cause it to move. During the start-up phase, while feeding inlet 1 with compressed air, the cylinder will adopt an uncontrolled speed as the inner cylinder chambers are at atmospheric pressure.
In order to avoid damage from uncontrolled movements, there should be a gradual insertion of pressure during the start-up phase.

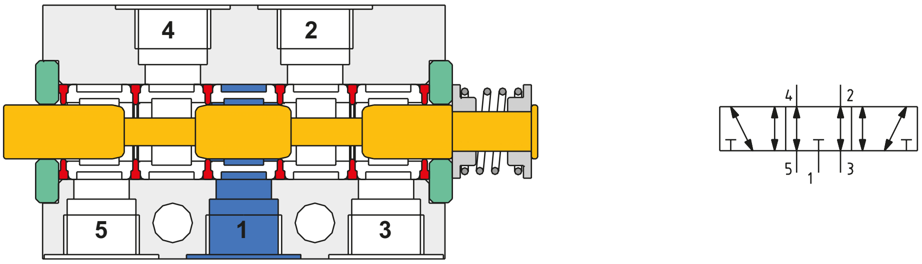


Fig. 41

Figure 42

5/3 PC - Pressure Centers: inlet 1 is in communication with outlets 2 and 4, exhaust ports 3 and 5 are closed.
The center position (third position) ensures inlet 1 is connected to both outlets 2 and 4 while the exhausts 3 and 5 are closed; this allows the pressurization of both chambers of the cylinder. In this position there is a thrust force acting on the piston in the positive direction, caused by the difference in the piston surfaces (areas) due to the presence of the rod on the front side of the cylinder.

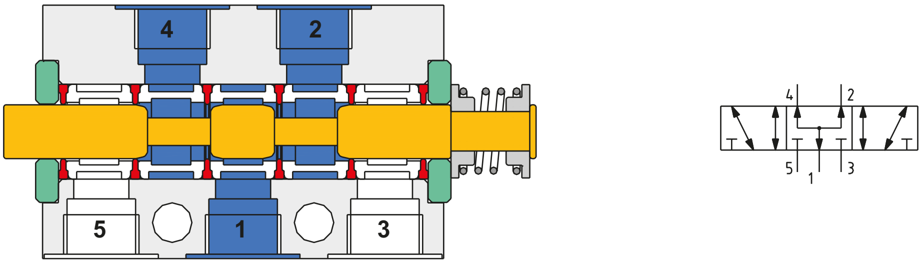


Fig. 42

Figure 43
Operation valves 5/3
The command coming from **A** acts on the left side of the pilot piston, moving the spool to the right, changing the direction of passage of the compressed air and compressing the return spring. Once the command is interrupted, the spring repositions the spool, which returns to the center position. The command coming from **B** passes through the hole in the spool, it reaches the left side of the pilot piston moving it to the left, compressing the repositioning spring. After removing the command, the spring repositions the spool to the central position.

The 5/3 CO valves and 5/3 CP valves may be replaced by a double 3/2 NC and 3/2 NO valve.

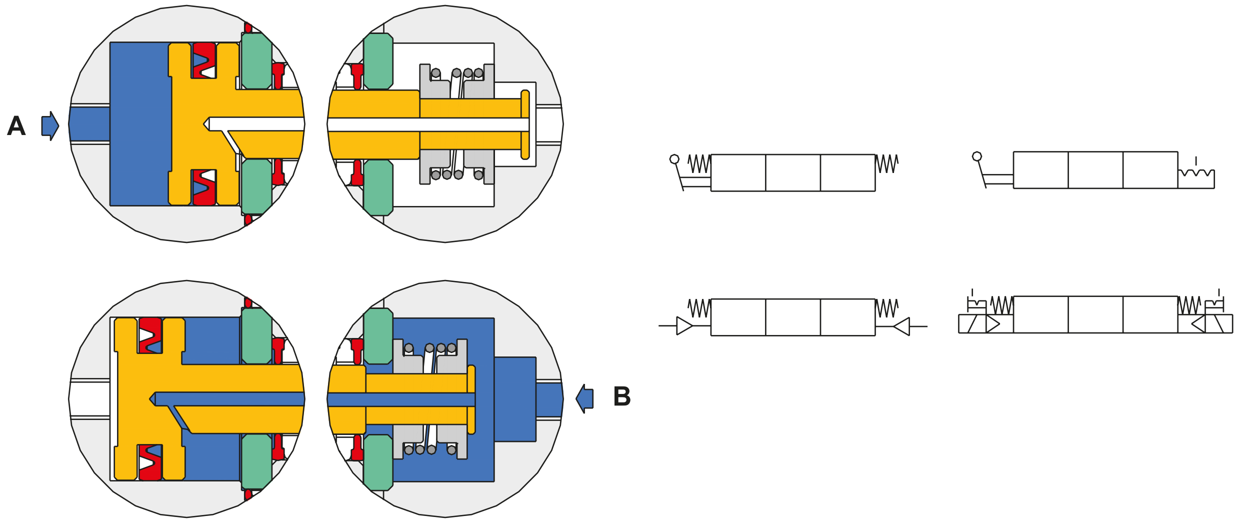


Fig. 43

Blocking valves

One of the functions required of pneumatic cylinders is the ability to stop the cylinder during both its positive and/or negative stroke. As we have seen, this function can be achieved with a 5/3-way closed centers (CC) valve, which closes both the supply inlet and valve exhaust. This function can also be obtained with blocking valves, which can be mounted directly on the cylinder ports. These valves, if appropriately mounted, offer similar results but with a higher degree of safety. The 5/3-way CC valve is subject to possible leakage over the spool seals, or between the fittings and tubes that could compromise the function of the CC valve. The blocking valves, being mountable directly on the cylinder ports, are not affected by problems on the tubes or fittings; having no intermediate connections they are less prone to leaks.
The function of the blocking valves is to interrupt the exhaust and air supply to the cylinders.
Blocking valves are categorised into two types: **unidirectional** and **bidirectional**.

Unidirectional blocking valves

Figure 44
Pos. A: the valve is in rest position, with no pilot signal.
Outlet 2 of the valve is mounted directly on the cylinder. The exhaust air from the chamber of the cylinder enters the blocking valve, which, in this state, is closed. This condition is generated by the effect of the spring and the pressure from the compressed air inside the cylinder acting on the plunger pushing it upwards, favouring the closure. The plunger acts as a unidirectional valve as it allows for the passage in one direction.
Pos. B: the valve is in rest position with no pilot signal; C/A is connected through inlet 1.
The C/A from the main valve enters the blocking valve through inlet 1 and exits from outlet 2 which, being connected to the cylinder chamber, allows the C/A to fill it. The passage from inlet 1 to outlet 2 is open because the pressure of the C/A from input 1 is sufficient to open the plunger.
Pos. C: presence of pilot signal, the valve is in exhaust position.
The C/A exiting the exhaust chamber of the cylinder enters the blocking valve through outlet 2, passes the depressed plunger, exits from inlet 1 and continues on to the main valve where it can be exhausted. To achieve the transition from outlet 2 to inlet 1, it is necessary to actuate the pilot piston of the blocking valve through the pilot signal 21.
The pilot signal 21, acting on the control piston, moves the unidirectional poppet downwards and opens it.

The diagram illustrates the connection of a double acting cylinder with an intermediate stop. By pressing one of the two 3/2-way NC solenoid valves, C/A is supplied to the active chamber of the cylinder, simultaneously controlling a blocking valve, which opens and allows the exhaust of C/A in the opposite chamber of the cylinder, the latter is in movement. In the rest position, the cylinder chambers are not supplied with C/A and cannot discharge because the blocking valves are closed: the cylinder is blocked.

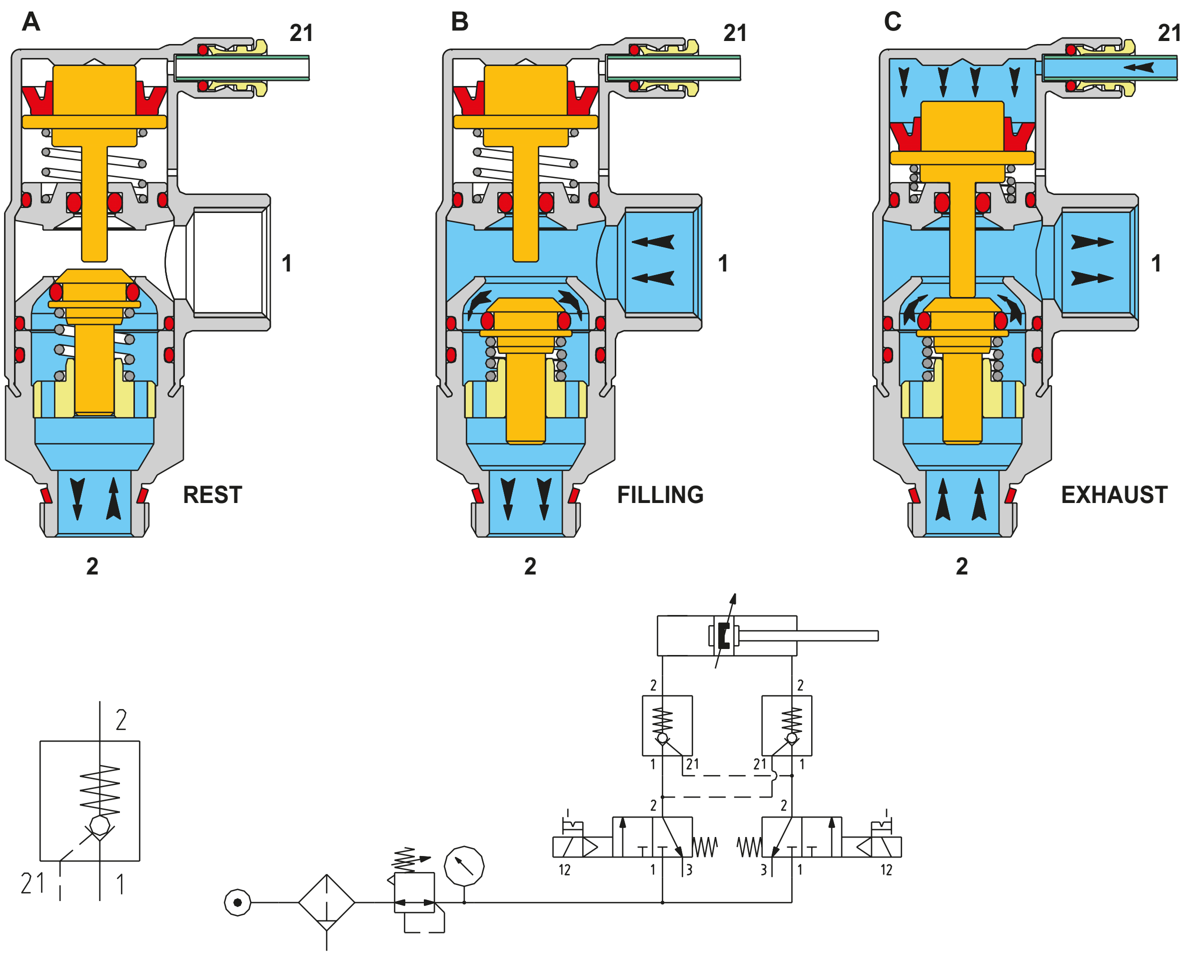


Fig. 44

Bidirectional blocking valves

Aesthetically, unidirectional and bidirectional blocking valves have no external differences, their operation is different however. This version is used when there is the need to close passages in all directions.

Figure 45
Pos. A: valve in rest position, no pilot signal.
The outlet 2 of the valve is mounted directly on the cylinder. The exhaust air from the chamber of the cylinder enters the blocking valve, which in this condition is closed. This condition is generated by the effect of the spring and the pressure from the compressed air inside the cylinder, which acts on the poppet pushing it upwards, favouring the closure. The poppet has no possibility to descend so the C/A connected to inlet 1 cannot pass. The valve has the function of a 2/2-way NC valve.
Pos. B: valve in actuated position, presence of pilot signal.
The C/A exiting the exhaust chamber of the cylinder enters the blocking valve through outlet 2, passes the depressed plunger and exits from inlet 1, continuing on to the main valve where it can be exhausted. To achieve the passage from outlet 2 to inlet 1 it is necessary to activate the control piston of the blocking valve through the pilot signal 12. The pilot signal 12, acting on the control piston, moves and opens the poppet.

The diagram illustrates the connection of a double acting cylinder with an intermediate stop. The C/A coming from the 5/2-way solenoid valve cannot enter the inside of the cylinder as the blocking valve is closed, likewise the exhaust air cannot leave the cylinder due to the other blocking valve which is also closed. By activating the 3/2-way NC solenoid valve, pilot signal 12 is received by both blocking valves. The poppet of each blocking valve is depressed and opens the passages from 1 to 2 and from 2 to 1, thus allowing the movement of the cylinder.
In the absence of the pilot signal 12, the spring repositions the poppet, which closes the passages, and the blocking valve is in the rest position.

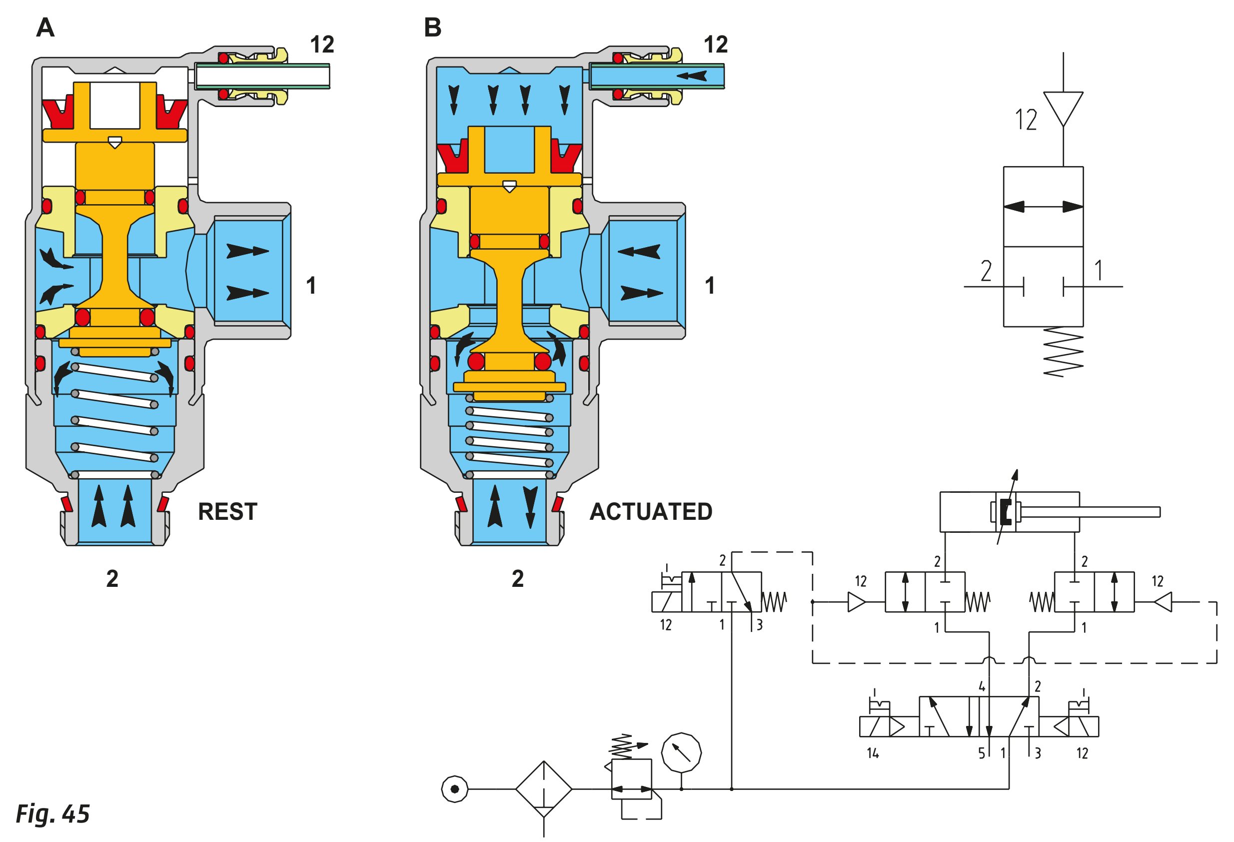


Fig. 45

Double 2/2-way and 3/2-way valves

Optimising space is often an important aspect for machine designers and as a consequence, reducing the overall dimensions for each function is an important parameter for the valve manufacturer to consider. To optimize the dimensions of valve blocks/valve islands, it is possible to integrate two 2/2-way or 3/2-way spools in one valve body. In this way the overall dimensions are not those of two individual valves side by side, but those of a bistable valve. Each 2 x 3/2-way or 2 x 2/2-way can comprise:

- two NC valves
- two NO valves
- one NO valve and one NC valve

Each valve, which is a part of the double 2/2-way or 3/2-way valve, is independent from the other and has its own pilot signal, which can be pneumatic or electric.

Figure 46
2 x 3/2-way NC valve electrically operated
In the body of the double valve there are two spools with a 3/2-way NC function with return springs and two sets of electric pilot signals. In the absence of pilot signals 12 and 14 (rest position) the channels from inlet 1 to outlets 2 and 4 are closed. With the pilot signal 12, the spool on the right side moves to the left, opening the passage of compressed air from inlet 1 to outlet 2, when the pilot signal is interrupted, the spring repositions the spool closing inlet 1, and connects outlet 2 to exhaust 3. With pilot signal 14, the spool on the left side moves to the right, opening the passage of compressed air from inlet 1 to outlet 4, when the pilot signal is interrupted, the spring repositions the spool closing inlet 1 and connects outlet 4 with exhaust 5. With the two pilot signals 12 and 14 activated simultaneously, the passages from inlet 1 to outlets 2 and 4 are open; in this case the airflow rate is reduced, as both outlets are open simultaneously.

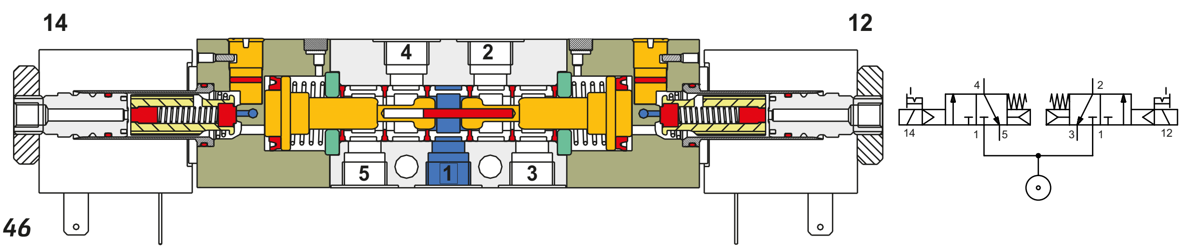


Fig. 46

Figure 47
2 x 3/2-way NO valve electrically operated

In the body of the double valve there are two spools with 3/2-way NO function with return springs and two sets of electric pilot signals. In the absence of pilot signals 12 and 14 (rest position) the channels from inlet 1 to outlets 2 and 4 are open. With the pilot signal 10 on the right, the spool on the right side moves to the left closing the passage of C/A from inlet 1 to outlet 2, which is put in communication with the exhaust port 3. When the pilot signal is interrupted, the spring repositions the spool re-opening the passage between inlet 1 and outlet 2.
With the pilot 10 on the left, the spool on the left side moves to the right closing the passage of C/A from inlet 1 to outlet 4, which is put in communication with the exhaust port 5. When the pilot signal is interrupted, the spring repositions the spool, re-opening the passage between inlet 1 and outlet 4. With the two pilot signals 12 and 14 activated simultaneously, the passages from inlet 1 to the outlets 2 and 4 are closed and the respective exhausts 3 and 5 are opened.

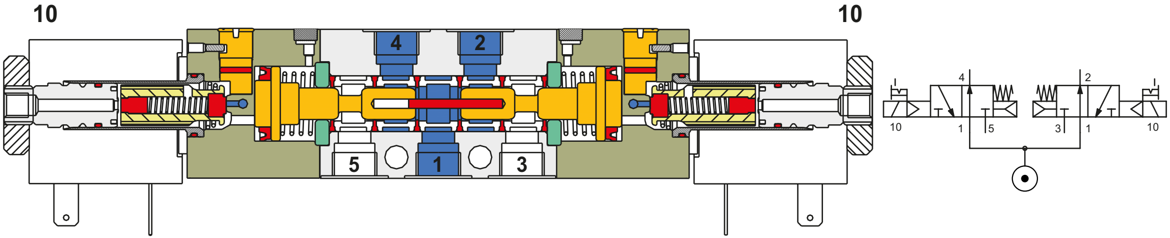


Fig. 47

Figure 48
An NO valve and an NC valve, electrically operated

In the body of the double valve there are two spools, one with 3/2-way NC function, one with 3/2-way NO function, with their respective return springs and two sets of electric pilot signals. In the absence of pilot signals (rest position) there is passage of C/A from inlet 1 to outlet 2 through the 3/2 NO valve, while outlet 4 is in communication with exhaust 5 through the 3/2 NC valve. With the pilot signal 10 on the right side, the spool moves to the left closing the passage of C/A from inlet 1 to outlet 2, which is put in communication with the exhaust 3. When the pilot signal is interrupted, the spring repositions the spool re-opening the passage between inlet 1 and outlet 2.
With the pilot signal on 14 the spool on the left side moves to the right, opening the passage of C/A from inlet 1 to outlet 4. When the pilot signal is interrupted, the spring repositions the spool re-closing inlet 1 and putting outlet 4 in communication with exhaust 5. When pilot signals 10 and 14 are activated simultaneously, the rest position is inverted, i.e. inlet 1 is in communication with outlet 4 and outlet 2 is communicating with exhaust 5.

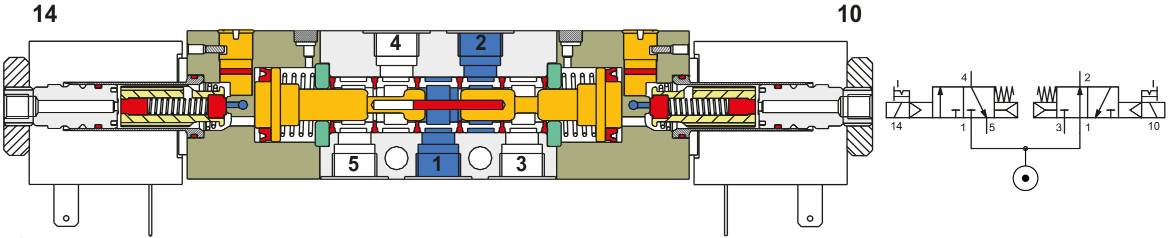


Fig. 48

The double 3/2-way NC and NO versions can replace the 5/3-way CO and 5/3-way CP valves respectively.
The 2 x 2/2 version has the same operating principle.

Signal processing valves

“Logic valves” or “logic functions” are pneumatic valves with reduced dimensions and flow rates, normally, low-pressure signals are sufficient for piloting. They are particularly suitable for processing signals in order to achieve a work sequence. These valves are generally poppet valves with the following functions:
NOT: corresponds to the operation of a monostable 3/2-way, NO valve, pneumatically operated and mechanical spring return.
YES: corresponds to the operation of a monostable 3/2-way NC valve, pneumatically operated and mechanical spring return.
AND: as by definition, this logic valve requires two continuous incoming signals to generate an output, and not necessarily simultaneously. This is sometimes called a “Select valve”.
OR: as by definition, this logic valve requires at least one of the two input signals to generate an output signal.
Memory: corresponds to a bistable 5/2-way valve pneumatically operated.
Signal amplifier: in the presence of a low-pressure pilot there is a high-pressure output.
Pneumatic sensors of the sender receiver type (interruption of air stream): are an alternative to mechanically operated sensors, a mechanical contact is not necessary, it is sufficient for an object in their field of action to generate an output signal.

Logic function NOT

The logic NOT function is a **3/2-way NO** monostable pneumatically operated valve. The difference between a normal 3/2-way valve and a NOT function is that the latter requires a very low-pressure value for the pilot signal (0,3 *bar*).

One of the most common uses of this function is to signal the end position of a cylinder. During movement, the value of the pressure in the exhaust chamber remains at a constant value and then decreases to the vicinity of the limit switch. This value is sufficient to operate the NOT switch which only activates when the piston rod/piston ceases its movement, i.e. with atmospheric pressure in the chamber.

Figure 49
Pos. A: in the presence of the pilot signal, inlet 1 is closed and outlet 2 is in communication with exhaust 3. The piston rod/piston is at the negative end position the negative chamber is pressurized and the NOT is activated, (10). In the presence of the pilot signal, the piston **C** pushes down the **D**. The spring compresses and the **D**, through the seal **E** closes the passage of compressed air from inlet 1 to outlet 2, the passage from outlet 2 to exhaust 3 opens.
Pos. B: in the absence of a pilot signal, inlet 1 is open towards the outlet 2.
The piston rod/piston is at the positive end position and the negative chamber is at atmospheric pressure, the NOT is not activated, (10). In the absence of the pilot signal, the spring that was compressed extends and lifts **D** and piston **C**. It opens the passage through the seal **E**; input 1 is now in connection with outlet 2. The presence of pressure in outlet 2 is indicated by the extended indicator **F**.

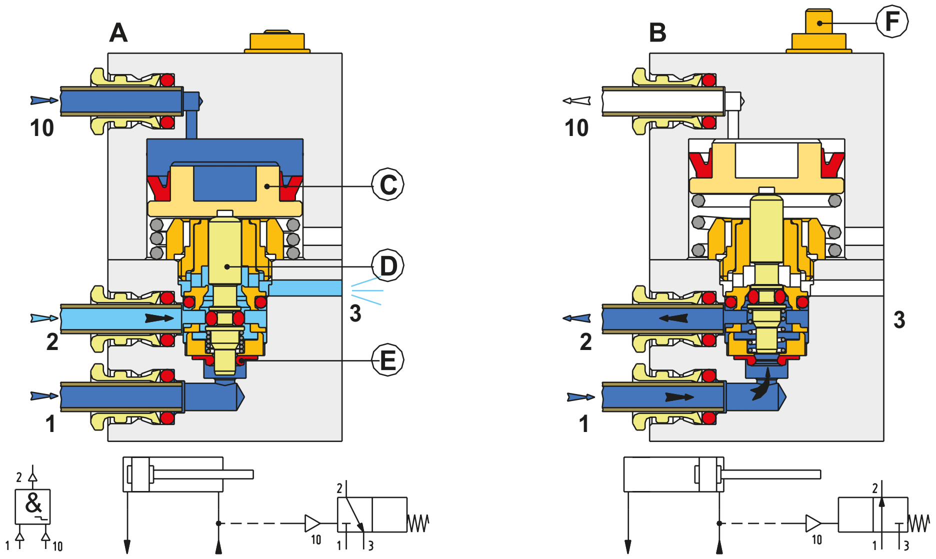


Fig. 49

When flow regulators are used for speed control, it is necessary to connect the NOT between the flow regulator and the cylinder. Unlike the sensors with mechanical control, these valves do not read the actual stroke end position, but respond to the presence of air inside the chambers. In the case of an eventual external blocking which would prevent the full stroke of the piston rod/piston, the NOT valve gives the output signal.

Logic function YES

The logic valve YES is a 3/2-way NC monostable pneumatically operated valve.
As in the previous situation, a very low-pressure value for the pilot signal (0.3 *bar*) is required.
Used less frequently than the NOT function, it finds applications in pneumatic logic circuits.

Figure 50
Pos. A: in the presence of a pilot signal, inlet 1 is open towards outlet 2.
The cylinder is at the negative end stroke position, and the negative chamber is pressurized, the pilot signal is under pressure (12). In the presence of the pilot signal, piston **C** pushes down the hollow stem **D**. The spring is compressed, and the hollow stem, through the seal **E**, opens the passage of C/A from inlet 1 to outlet 2. The seal **E** keeps the passage **D** of the stem closed. The presence of pressure in outlet 2 is indicated by the extended indicator **F**.
Pos. B: in the absence of a pilot signal, inlet 1 is closed and outlet 2 is in connection with exhaust 3.
The cylinder is at the positive end stroke position. The negative chamber is at atmospheric pressure, and there is no pilot signal (12). In the absence of a pilot signal, the spring, which was formerly compressed, is extended and lifts the hollow stem **D** and the piston **C**. The seal **E** is detached from the hollow stem closing inlet 1 and opening passage **D** on the hollow stem. Outlet 2 is in connection with exhaust 3.

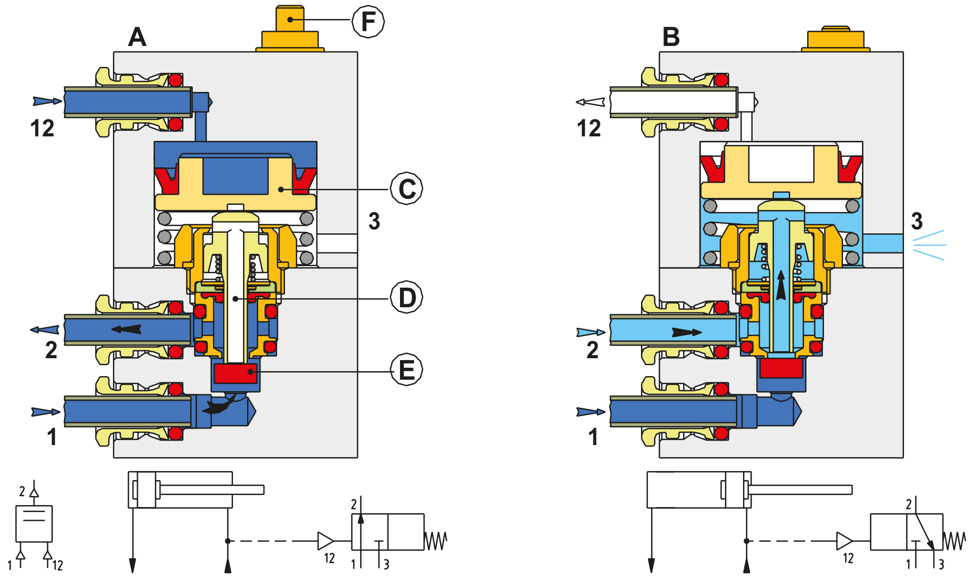


Fig. 50

In the situation whereby flow regulators are used for speed control, it is necessary to connect the YES between the flow regulator and the cylinder.

Logic functions OR and AND

The logic functions AND and OR are used in the design of pneumatic circuits, where certain conditions are required to allow the passage of pneumatic signals.

Logic function OR

This is a logic valve that has the function of a circuit selector.
It has three pneumatic connections: two inlets and one outlet.
To generate a signal at the outlet, the continuous presence of pressure in at least one of the two inlets is required.

Figure 51
Pos. 1: presence of inlet **P** on the upper side only. The incoming C/A pushes the seal **G** against the orifice located on the insert, the passage to the lower inlet **P** is closed. The passage to the outlet **A** is opened.
The presence of outlet **A** is indicated by the extended indicator **B**.
Pos. 2: presence of signal on the inlet **P** on the lower side only. The incoming C/A raises the seal **G** against the upper orifice of the valve body, the passage to the upper inlet **P** is closed. The passage to the outlet **A** is opened.
The presence of pressure in outlet **A** is indicated by the extended indicator **B**.
Pos. 3: absence of input signals. In the absence of pneumatic inputs there is no output. If there are two **P** inlets simultaneously, the first signal at outlet **A** is the fastest when the pressure is equal, however with differing pressures the first signal is always the one with the higher pressure. The indicator **B** due to the spring is in rest position.

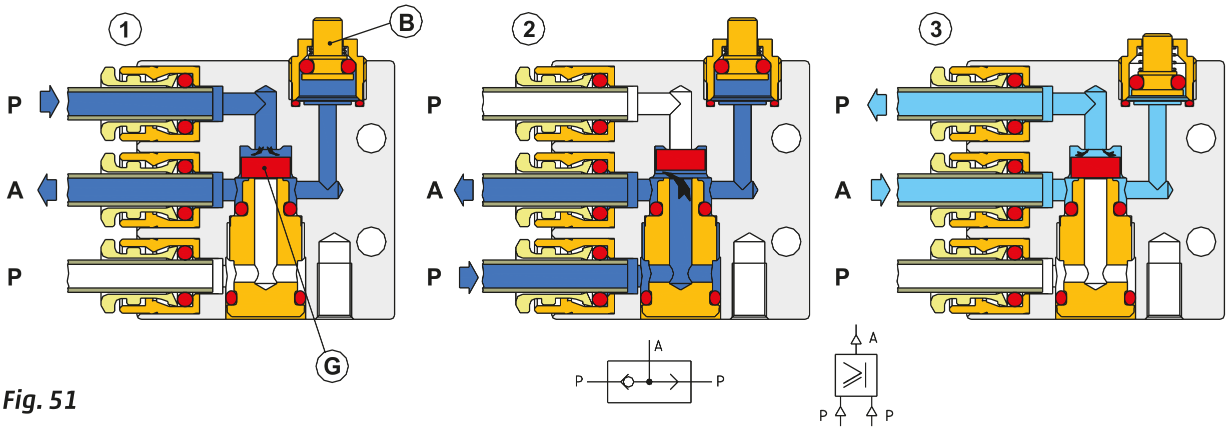


Fig. 51

Logic function AND

It has three pneumatic connections: two inlets and one outlet.
To generate a signal at the outlet, it is necessary to have the continuous presence of pressure in both of the two inlets. They need not necessarily be pressed simultaneously.
It is not sufficient to be used alone as a "Two hand control valve".

Figure 52
Pos. 1: presence of inlet **P** on the upper side only.
The pneumatic inlet **P** pushes the stem **C** downwards and its seals, acting on the orifice located on the insert, closing the passage of this inlet towards outlet **A**. In the opposite direction any pressure on outlet **A** can exhaust through the lower inlet **P**.
Pos. 2: presence of both upper and lower inlets **P**.
With the stem in the position determined by the previous pilot signal, the second pilot signal is free to move towards outlet **A**. The presence of outlet **A** is indicated by the extended indicator **D**. In the presence of two inlets with varying pressures **P**, the outlet **A** is always the signal with lower pressure.
Pos. 3: presence of inlet **P** on the lower side only.
The pneumatic inlet **P** lifts the **C** and its seals, acting on the orifice located on the insert closing the passage of this inlet towards outlet **A**. Any pressure on outlet **A** can exhaust through the upper inlet **P**. The Indicator **D** stem, due to the spring is in the rest position.

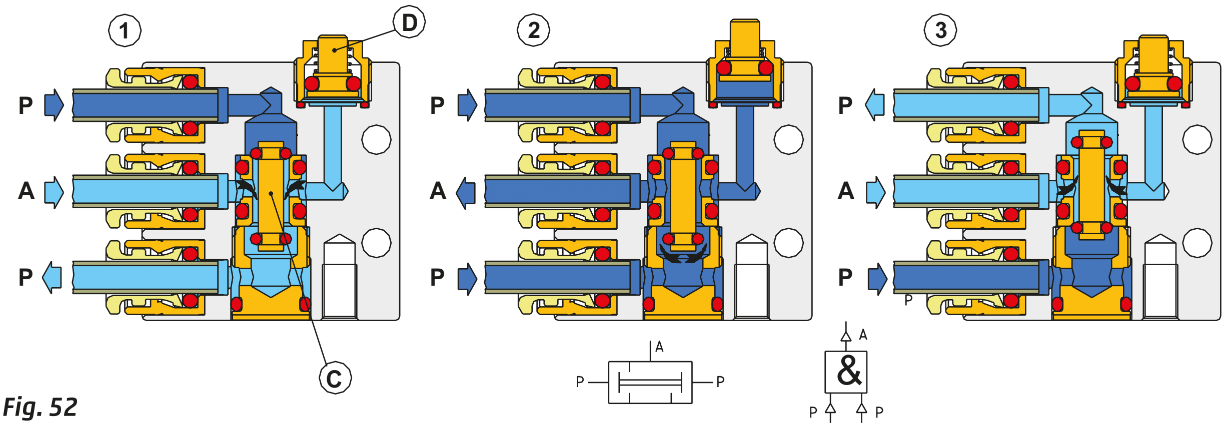


Fig. 52

Logic function Memory

The logic function Memory supplies a signal to the pneumatic sections of the circuit depending on the pneumatic command received and should remain in the position determined by the last pilot signal. Its operation is identical to that of a bistable pneumatically operated 5/2-way valve, with two differences:

- reduced dimensions, as in the signal processing valves a high flow rate is not required;
- presence of the manual override.

Figure 53
Pos. A: pilot signal 12.
In the presence of pilot signal 12 the grey spool moves to the right allowing the passage of C/A from inlet 1 to outlet 2 and from outlet 4 to exhaust 5. The spool pushes the right manual override outwards.
Pos. B: absence of pilot signals.
As by definition this valve function memorizes the position determined by the last pilot received. The state does not change.

Figure 53
Pos. C: pilot signal 14.
In the presence of pilot signal 14 the grey spool moves to the left allowing the passage of C/A from inlet 1 to outlet 4 and from outlet 2 to exhaust 3. The spool pushes the left manual override outwards.
Pos. D: absence of pneumatic pilot signals, activation through manual override.

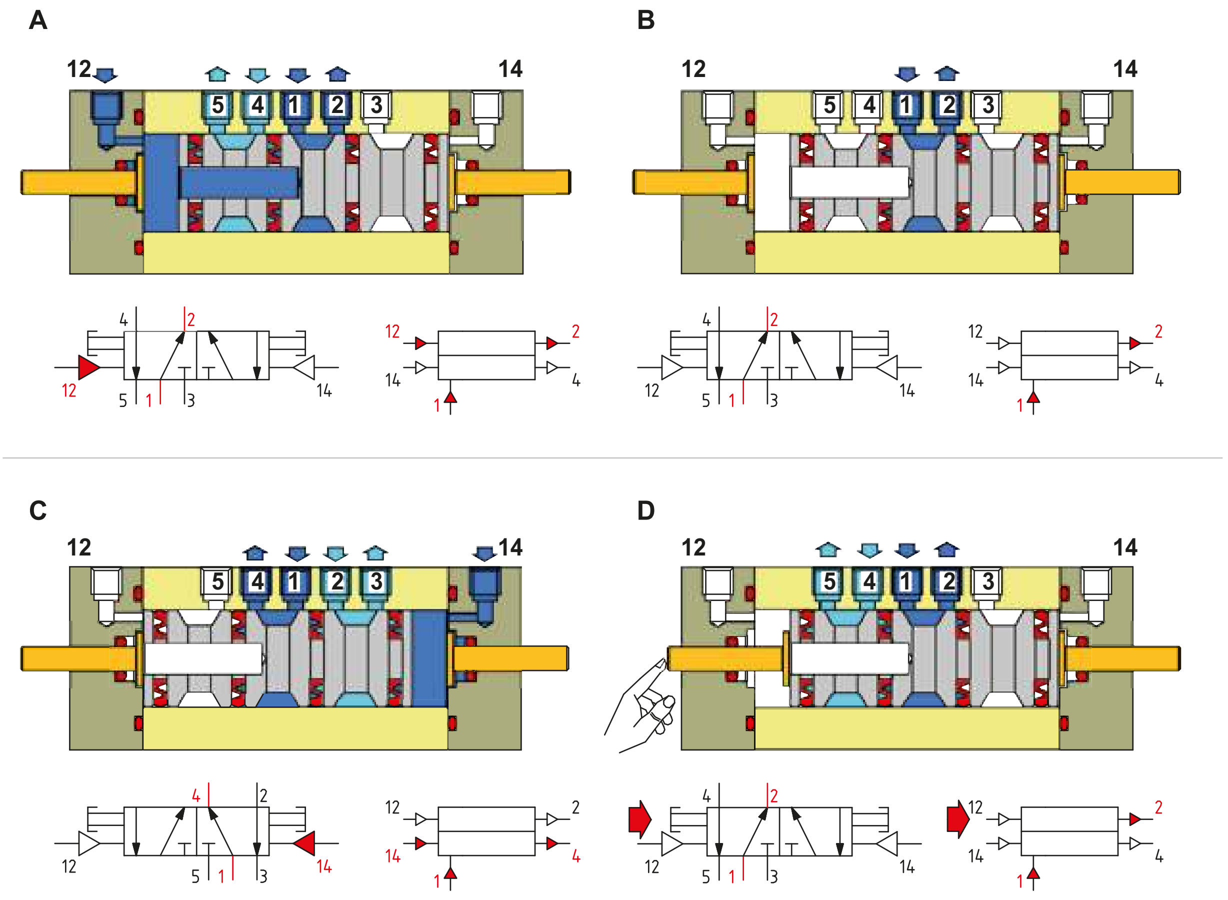


Fig. 53

The manual overrides are operable only in the absence of pilot signals. They have the same function.

Signal amplifier

The signal amplifier is a monostable 3/2-way NC pneumatically operated valve. Also in this case the pilot signal pressure is very low (0.03 to 0.6 *bar*), due to the large inner diaphragm **C**. The amplifiers are particularly suitable when paired with sensors of the sender receiver type (interruption of air stream), or to amplify those utilities whose output provides a signal whose pressure values correspond to those indicated above.

Figure 54
Pos. A: absence of pilot signal (12).
The passage of C/A from inlet 1 (this connection is not visible as it is located on the rear side of the amplifier) to outlet 2 is closed. The seal **E**, driven by the pressure from inlet 1 and the force exerted by the spring **M**, closes the passage towards outlet 2. The C/A coming from inlet 1 passes through the orifice on the hollow stem on which the seal **E** is located, it transverses plate **D** until it arrives under the diaphragm **C**, which rises. The C/A fills the volume/chamber below the diaphragm **C** creating an air spring, which keeps the diaphram elevated. This chamber is open towards the atmosphere through a very small-calibrated hole. The C/A coming from outlet 2 is exhausted through the exhaust port 3.
Pos. B: presence of the pilot signal (12).
In the presence of the pilot signal (12), the diaphram **C** is lowered as the pressure of the C/A in the chamber below being continuously exhausted has a lower value. While descending, the diaphragm closes the upper calibrated orifice (magnification **F**), compressed air no longer escapes through this small calibrated hole.
By closing the orifice, the C/A, which was previously exhausted into the atmosphere, impacts upon the plate **D** (magnification **G**) pushing it downward. The plate **D** is mounted on the stem that moves downward, opening the passage through the seal **E** (magnification **H**). Inlet 1 is now in communication with outlet 2.

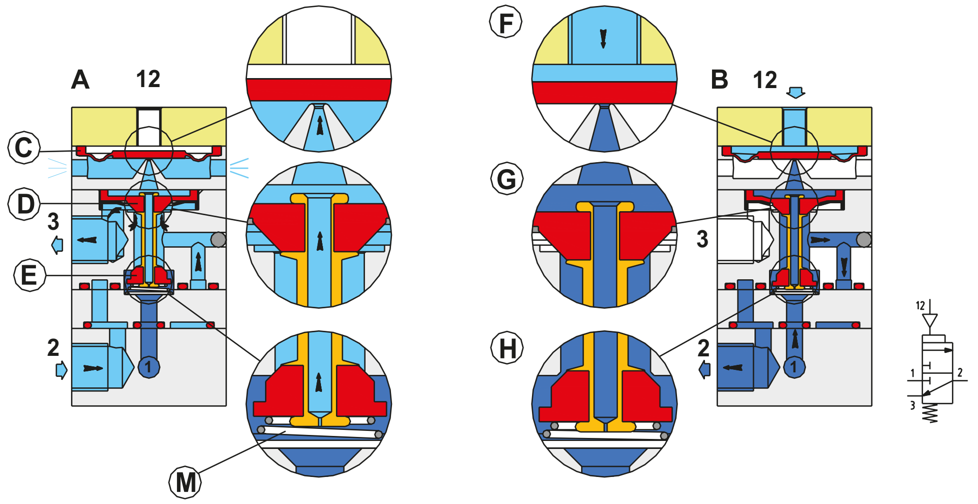


Fig. 54

In the pneumatic symbol, the dimension of the box referring to the pneumatic operation is larger than normal indicating that this is a valve with a low-pressure activation.

Pneumatic sensors of sender/receiver type (interruption of air stream)

In some applications it may be advantageous to use the sensors that don't come in contact with the product, and can operate in the absence of electricity or where the work environment requires the use of "self-cleaning" sensors. The pneumatic sensors, normally one sender and one receiver, behave as photocells in the sense they interrupt the pneumatic signal when an object is placed between them. These sensors are especially effective when their distance is no more than 80 *mm*. The shape of the piece placed between the two sensors can vary the sensitivity of the system.

Figure 55
Pos. A: there is no object inserted between the sender and receiver sensors.
The two sensors are powered with low pressure and emit a stream of C/A flowing towards each other. The different size of the nozzles present in the two sensors causes a variation in the speed of the two air streams generated. The sender sensor, having a smaller diameter than the orifice, generates a flow with a speed greater than the flow generated by the receiver sensor. The flow produced by the receiver sensor is unable to enter the atmosphere because of the faster opposing flow. A flow obstruction of the receiver sensor is created, and not being able to be released into the atmosphere, a pressure increase is created at outlet 2. This increase in pressure is able to drive the pressure amplifier connected to outlet 2. The amplifier returns a pneumatic signal.
Pos. B: there is an object placed between the sender and receiver sensors.
The flow of C/A coming from the receiver sensor, since it is no longer obstructed by the flow from the sender sensor, is released into the atmosphere. The receiver sensor no longer directs the flow towards its outlet 2.

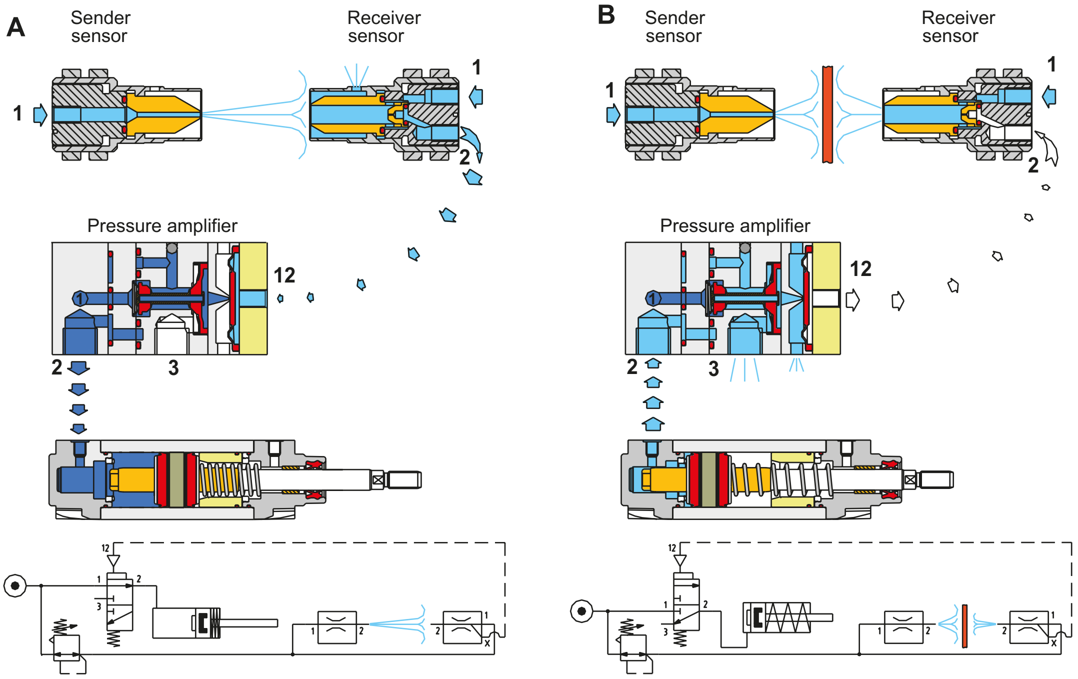


Fig. 55

Nominal flow rate

The following factors must be considered when selecting components:
- The distribution line must be dimensioned to fulfil the requirements of the system to be served.
- The larger the flow section, the greater the possible flow rate.
- Any request of air always creates a pressure drop.
- Increasing the request of air, with the same flow section, increases the drop in pressure.

Figure 56
Similar to the distribution line, valves must also be sized correctly in order to be able to provide a quantity of compressed air sufficient to that required by the equipment in use. The selection should not be based on the size of the connection, but in reference to the flow rate indicated by the technical data of the product.

In order to have one size as reference, the ISO Standards (International Standard Organization) prescribes the use of the term **Nominal Flow** rate as that which every valve effectively supplies per minute in defined test conditions:
- Regulated pressure 6 *bar*
- Ambient temperature 20 °C
- Pressure drop (Δp) 1 *bar*

Conversion table of the most common units of measurement.

1 *kv*	*Kv* 0,06	C_v 0,069	*f* 0,057	Q_n 67
1 *Kv*	C_v 1,179	*f* 1,000	Q_n 1149	*kv* 16,67
1 C_v	*f* 0,83	Q_n 962	*kv* 14,42	*Kv* 0,85
1 *f*	Q_n 1159	*kv* 1,85	*Kv* 0,97	C_v 1,205
1 Q_n	*kv* 0,015	*Kv* 0,0009	C_v 0,001	*f* 0,0009

kv = flow of water with Δ*p* = 1 *bar* at 20°C [*l/min*]

Kv = flow of water with Δ*p* = 1 *bar* at temperature ranging from 5°÷40° $[m^3/hour]$

C_v = Flow of water with Δ*p* = 1 *PSI* [*US Gallons/min*]

f = as above but expressed in *Imperial Gallons*

Q_n = nominal flow rate with inlet pressure 6 *bar* and Δ*p* = 1 *bar* at temperature of 20 °C [*Nl/min*]

Example: conversion of a flow rate of 17 *kv* into *Qn*:

1 *kv* = 67 Q_n [*Nl / min*]   17 *kv* = 17 ∗ 67 Q_n

A flow rate of 17 *kv* corresponds to a Q_n of 1133 *Nl/min*.

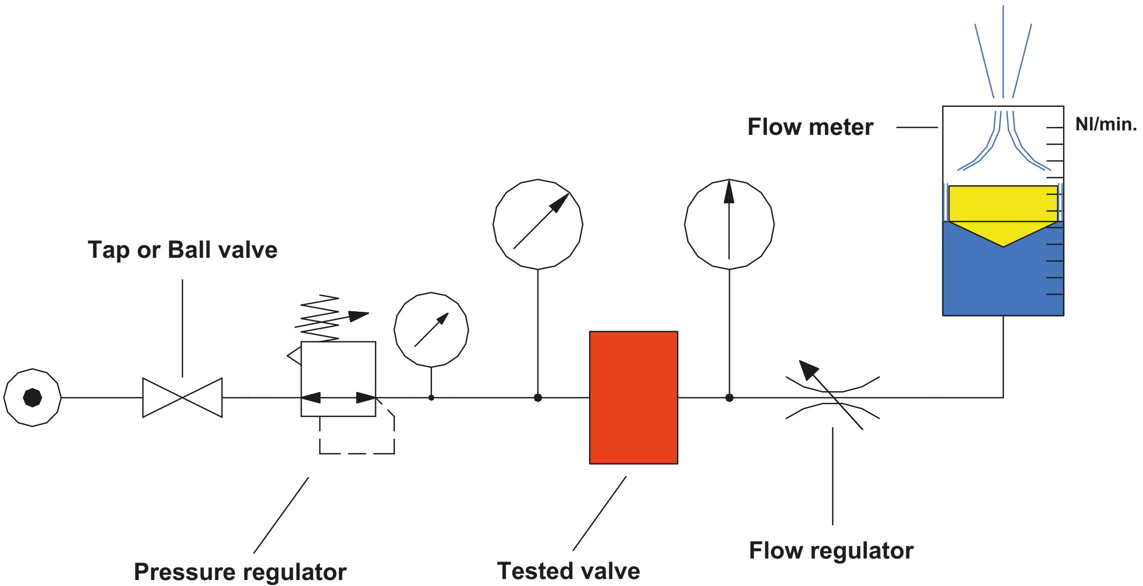


Fig. 56

Sizing of directional control distribution valves and connecting tubes

In a pneumatic system a cylinder must move a given load and this must be executed within a designated time. The first requirement has been addressed in the previous chapters; we now analyze the latter requirement.

The following data must first be determined:
- The volume to fill, for example the cylinder chamber used.
- The time required to complete the stroke.
- The operating pressure.

Valve sizing
Assume we have a cylinder with the following characteristics:

diameter $D = 50\ mm$,

stroke length $c = 250\ mm$ stroke,

operating pressure $P = 6\ bar$,

timing of the positive stroke $t = 1{,}5\ sec$.

Calculation of the volume V of the cylinder:

$$V = \text{Area} * \text{Stroke}$$

$V = r^2 * \pi * c$ $\quad$ $V = (25\ [mm])^2 * \pi * 250\ [mm]$ $\quad$ $V = 490.625\ mm^3$ $\quad$ $V = \mathbf{0{,}49\ dm^3}$

Calculation of the amount of required air Q_s to fill the volume V at a pressure of 6 bar in a time $t = 1{,}5\ sec$.

$Q_s = V * P_{abs}$ $\quad$ $Q_s = 0{,}49\ [dm^3] * 7\ [bar]$ $\quad$ $Q_s = \mathbf{3{,}43\ Nl}$

This amount should be provided in a time $t = 1{,}5\ sec$, which expressed in Q_r (per minute) becomes:

$Q_r = (Q_s / t) * 60$ $\quad$ $Q_r = (3{,}43 / 1{,}5) * 60$ $\quad$ $Q_r = \mathbf{137\ Nl / min}$

The quantity of air required for the valve to move a cylinder:

of diameter $D = 50\ mm$

stroke $c = 250\ mm$

in a time $t = 1{,}5\ sec$.

is ***137 Nl / min***

Figure 57
From the graph it is possible to detect the flow characteristics of two different valves which have M5 and M7 threads respectively.
The required flow rate Q_r can be obtained from both valves, which have a limited pressure drop (Δp) which varies from 0.1 to 0,4 bar.
Despite having a cylinder of fixed dimensions as in this case, it is not necessary to size the valve in relation to the connection on the heads, but it is possible to use valves with the best price/size/flow ratio.

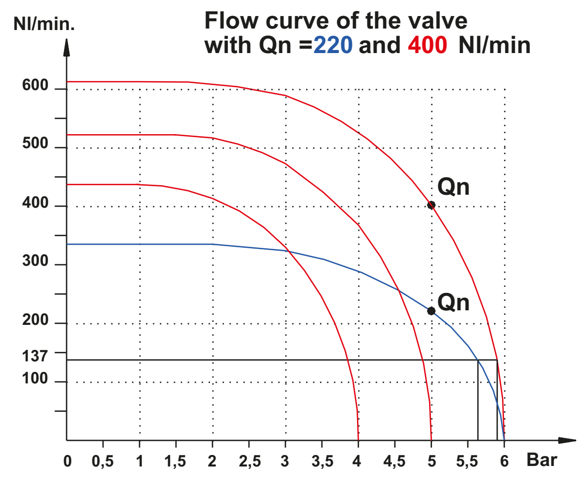


Fig. 57

Figure 58

Tube Sizing

For the selection of the tubes it is necessary to check the flow characteristics according to their length and diameter (see *Fig. 58*). Incorrect sizing will consequentially increase Δp with repercussions on travel time of the cylinders, and therefore on the cycle. When several components are aligned in sequence, the resulting flow rate is not of the component with the lowest value. To calculate the value it is necessary to introduce a new variable called "**conductance**".

The conductance is the ratio between the flow rate value in free flow Q and the value of the absolute pressure.

$$C = \frac{Q\,[Nl/min]}{P_{rel}\,[bar] + P_{atm}\,[bar]}$$

Taking as reference the valve with $Q_n \cong 400$ *Nl/min* we see that the value of flow in free air at 6 *bar* is $Q \cong 610$ *Nl/min*, from which the conductance is equal to:

$$C = \frac{Q}{P_{rel} + P_{atm}} \qquad C = \frac{610}{6+1} \qquad C = \mathbf{87{,}14}\ \boldsymbol{Nl/min * bar}$$

If the supply pressure were 5 *bar*:

$$C = \frac{520}{5+1} \qquad C = \mathbf{87{,}14}\ \boldsymbol{Nl/min * bar}$$

If the supply pressure were 4 *bar*:

$$C = \frac{435}{4+1} \qquad C = \mathbf{87{,}14}\ \boldsymbol{Nl/min * bar}$$

We conclude that the value of conductance does not vary by changing the supply pressure.

Generally in catalogues, the nominal flow rate Q_n is indicated, calculated according to UNI ISO 8778 with a supply pressure of 6 *bar* and Δp 1 *bar.* Taking the measured values on the graph, we observe that the free air delivery with a supply pressure of 6 *bar* is:

$$Q \cong \mathbf{610}\ \boldsymbol{Nl/min}$$

The conductance of this valve as in previous calculations is:

$$C = \mathbf{87{,}14}\ \boldsymbol{Nl/min * bar}$$

Also from the graph we observe that with a supply pressure of 6 *bar* and Δp 1 *bar* the flow rate is:

$$Q_n \cong \mathbf{400}\ \boldsymbol{Nl/min}$$

Taking the value of Q_n and dividing it by the value of C we obtain a coefficient X that experimental tests have determined with good approximation, to be valid for all the sections traversed by a fluid.

$$X = \frac{Q_n}{C} \qquad X = \frac{400}{87{,}14} \qquad X \cong \mathbf{4{,}6}$$

Another way to calculate the conductance of an element is:

$$C = \frac{Q_n}{X}$$

The value assumed by conductance of many elements in series is defined by the formula:

$$C = \sqrt[3]{\frac{1}{\frac{1}{C_1^3} + \frac{1}{C_2^3} + \frac{1}{C_3^3} + \frac{1}{C_n^3}}}$$

Where *C* is the conductance of each element considered singularly.
We insert the data (calculated or obtained from the graph of the tube flow) into the formula. (*Fig. 58*).

$Q_{n1} = 320$ *Nl/min* tube diameter 6/4 $L = 2{,}5$ *m*. from the air treatment to the valve

$Q_{n2} = 400$ *Nl/min* valve

$Q_{n3} = 320$ *Nl/min* tube diameter 6/4 $L = 2{,}5$ *m*. valve-to-cylinder

The respective values of conductance are:

$C_1 = \frac{Qn1}{X}$	$C_1 = \frac{320}{4{,}6}$	$C_1 =$ **69,56 *Nl / min* ∗ *bar***
$C_2 = \frac{Qn2}{X}$	$C_2 = \frac{400}{4{,}6}$	$C_2 =$ **86,95 *Nl / min* ∗ *bar***
$C_3 = \frac{Qn3}{X}$	$C_3 = \frac{320}{4{,}6}$	$C_3 =$ **69,56 *Nl / min* ∗ *bar***

By entering values into the formula you obtain the value of the total conductance:

$$C_{tot} = \sqrt[3]{\frac{1}{\frac{1}{69{,}56^3} + \frac{1}{86{,}95^3} + \frac{1}{69{,}56^3}}}$$

$C_{tot} =$ **51,18 *Nl / min* ∗ *bar***

From which:

$Q_n = C * 4{,}6$ $Q_n = 51{,}18 * 4{,}6$ $Q_n =$ **235 *Nl / min***

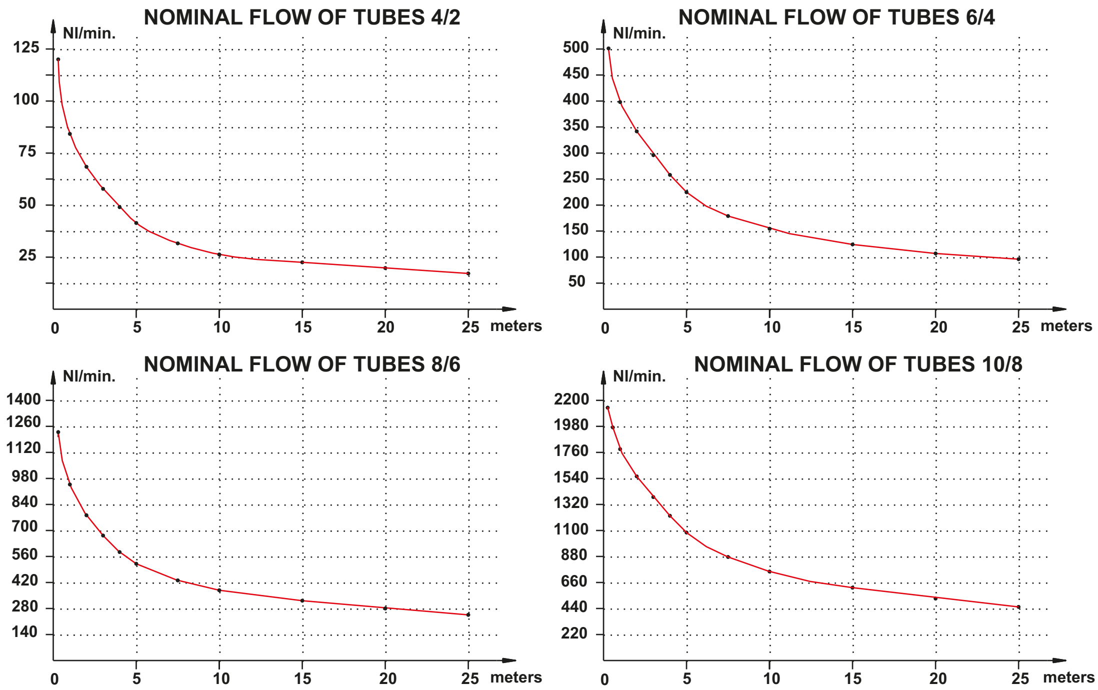


Fig. 58

Final conclusions:
The cylinder in question, with a diameter of 50 *mm*, stroke length 250 *mm*, to complete the stroke in a time of 1,5 *sec*. requires at least 137 *Nl/min*. Assuming we use a valve with a flow rate of Q_n = 400 *Nl/min* and various connecting tubes with a 6/4 diameter with total length of 5 *mt*. the nominal flow rate of the system becomes:

$$Q_n = \mathbf{235\ Nl / min}$$

This flow rate is greater than required, and therefore fulfils the request; also, the pressure drop of the system is less than 1 *bar* and therefore has a large safety margin.

Interception valves

Non-return or unidirectional valves.
These valves block the passage of compressed air in any undesired direction. As a consequence of the phenomenon of expansion of gases, the direction of flow always points towards the chamber with the lower pressure. If the C/A contained in two connected containers (regardless of their volume or distance) is not intercepted, the compressed air disperses and balances the pressure.

Normally the distribution of compressed air includes an initial receiver (accumulator tank) located upstream of the distribution network. The pneumatic devices connected to the network can include additional small compensation tanks. For the phenomenon described above, if the pressure in the initial accumulator tank should decrease, there would be an undesired transition of the compressed air, seeking to return upstream from the compensation storage tanks. To avoid this process, non-return or unidirectional valves are used.

Figure 59
Pos. 1: the unidirectional valve comprises a body which houses a poppet with its own seal as well as a spring. The compressed air that is only able to pass from left to right must have a pressure such as to overcome the spring force and the downstream pressure.
Pos. 2: when the value of the downstream pressure combined with the thrust of the spring is higher than the upstream pressure, the poppet moves to the left closing the passage.

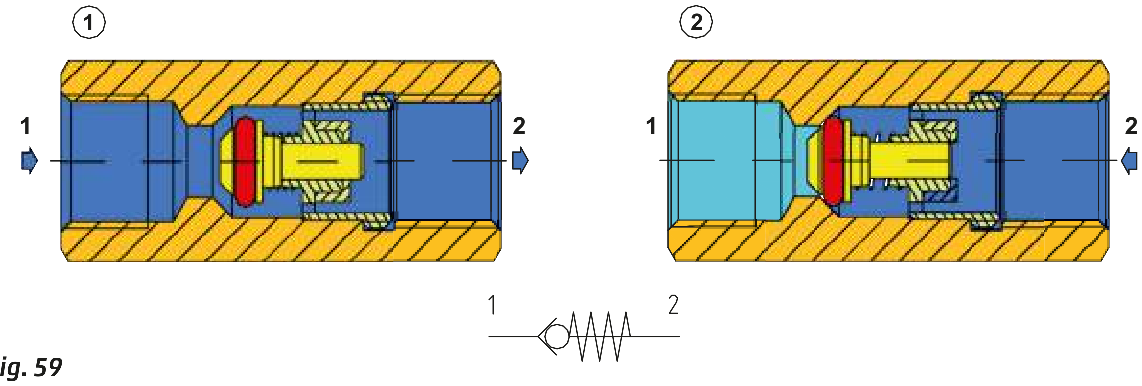


Fig. 59

Quick exhaust valves.
This valve is mounted directly on the cylinder ports or a chamber, and diverts the flow of the C/A, exhausting it directly into the atmosphere. This method stops the C/A in exhaust to return back through the tubing and the control valve, allowing a reduced exhaust time and consequently accelerating the movement of the cylinder.
The absence of an internal spring allows the quick exhaust valve to switch even with very low pressure.

Figure 60
Pos. 1: the body of the quick exhaust valve consists of two parts screwed together, inside which a lip seal is positioned. The C/A arriving from inlet 1 moves the seal towards the right, closing the passage to exhaust 3 and opening the passage towards outlet 2 connected to the cylinder chamber.
Pos. 2: when the C/A of the cylinder is to be exhausted as there is no more pressure at inlet 1, it passes back through outlet 2, moves the seal which closes inlet 1 and opens exhaust 3.

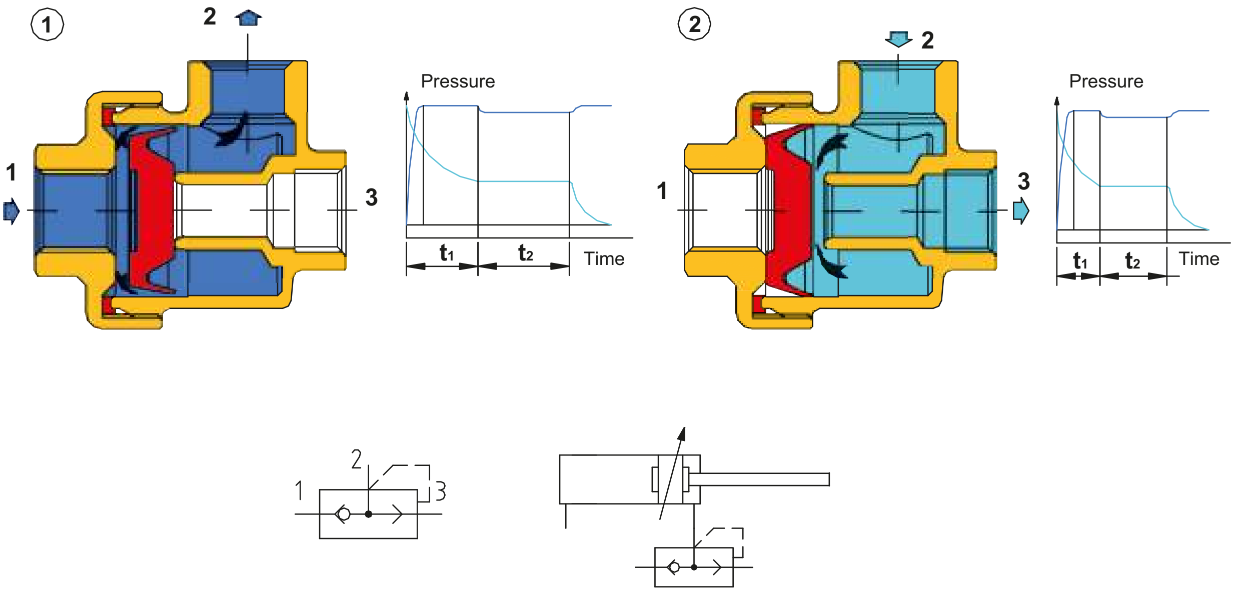


Fig. 60

The diagrams show the different behavior of the C/A in the two chambers of a double acting cylinder in the presence or absence of a quick exhaust valve.

The value t_1 indicates the time that elapses between the change of the position of the valve (including the pressurization time of the cylinder) and the beginning of the movement of the piston. Observe how the curves, which represent the exhaust phase, vary in the two graphs. The value t_2 indicates the duration time of the piston stroke. This value is noticeably different in the two graphs because the pressure in the exhaust is released immediately into the atmosphere without it going back through the connecting tubes or the control valve.

Note: it is not advisable to use quick exhaust valves combined with 5/3 CC valves.

Flow control valves

Part 1

The flow control valves regulate the passage of compressed air through the variation of their internal cross section. By regulating the flow, it is possible to adjust the speed of the pistons in pneumatic cylinders. The control should always be performed on the exhausting chamber. Incoming air is only regulated on single acting cylinders.

Unidirectional flow regulator

The connection 1 connects to the volume to be regulated and connection 2 is the connection directed towards the main directional valve.

Figure 61

Pos. A: the flow of compressed air exiting the chamber enters the regulator via connection 1. The compressed air encounters lip seal **C** mounted on cartridge **B** and expands to contact with the body of the regulator, creating the unidirectional function. The compressed air is therefore forced to pass through the reduced cross section created by the conical part of the adjusting screw **A** and the orifice on the cartridge **B**.

Pos. B: the incoming flow of compressed air to the chamber enters the regulator via connection 2. The lip seal **C** gives way, opening the passage and allowing the transit of flow both inside and outside the cartridge **B**. In this direction the flow is not regulated.

Bidirectional flow regulator

Pos. C: the flow of compressed air exiting the chamber enters the regulator via connection 1. In this situation neither the cartridge **B** or its lip seal are included. The compressed air is forced to pass through the reduced cross section created by the conical part of the adjustment screw **A**, which by moving upwards or downwards, changes the passage cross section between cone and the orifice **D**.

Pos. D: the incoming flow of compressed air through connection 2 is forced to pass as in the previous case, through the reduced cross section created by the conical part of the adjustment screw **A**, which through its upwards or downwards movement, changes the passage cross section between the cone and the orifice **D**.

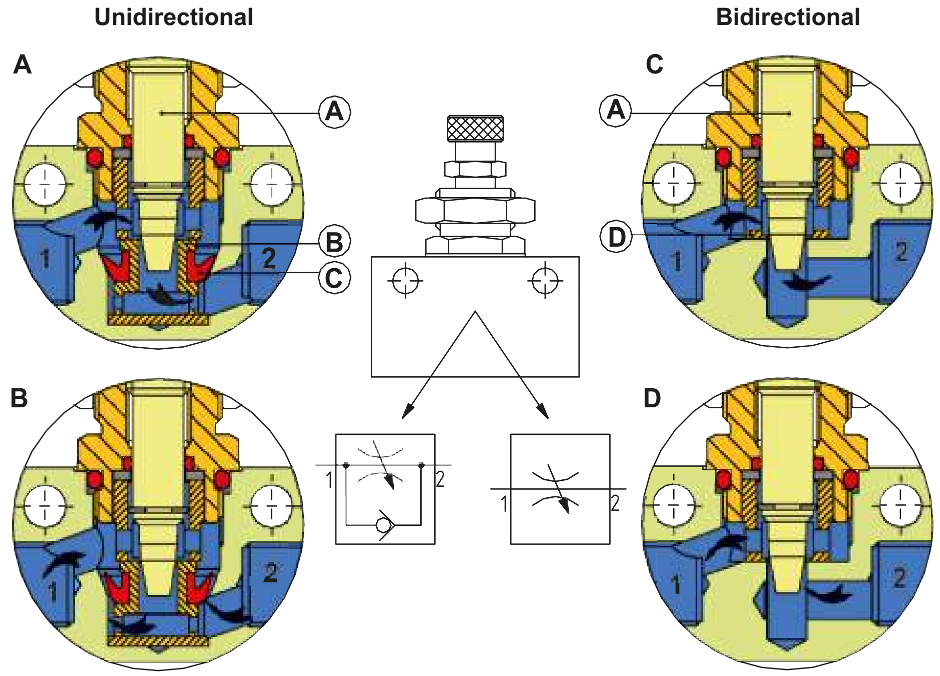


Fig. 61

Figure 62
To select the correct dimensions of the flow regulator, it is advisable to consider the following:

- The value of the maximum flow rate with the adjusting screw fully open.
- The flow rate in the non adjustable direction: a certain amount of compressed air must reach the thrust chamber of the cylinder to ensure constant pressure. During the movement of the cylinder, the volume of the thrust chamber continually changes and the amount of compressed air entering must always be able to compensate for this volume change, otherwise the movement would be erratic.
- The gradient of the curve indicates the flow rate based on the number of turns of the adjusting screw: the volume of compressed air within the chambers of the cylinder depends on the diameter, the stroke and the supplied pressure. Referring to graphs illustrating the flow characteristics, allows for the selection of the most appropriate flow regulator that enables the most optimal and precise adjustment.

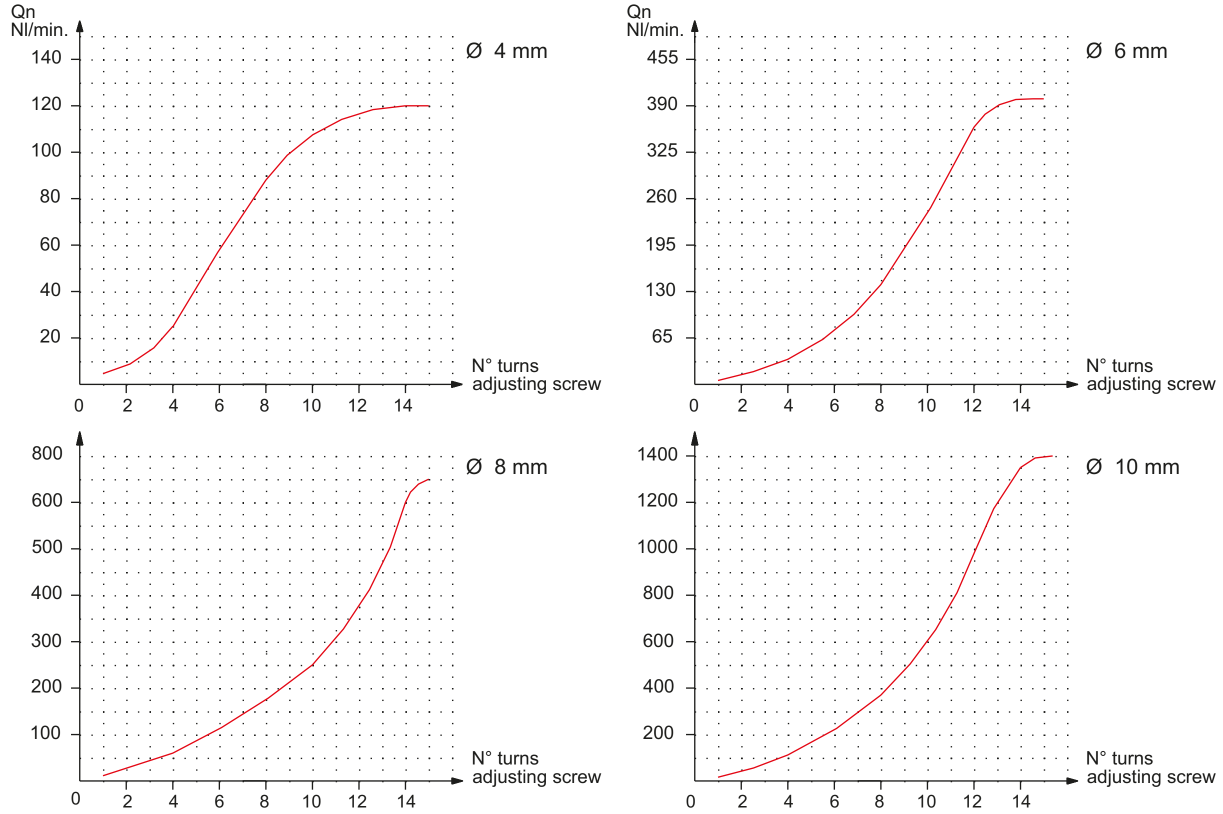


Fig. 62

Part 2
The most commonly used flow regulation valves are unidirectional valves, in this section we offer a further analysis of their features.

Figure 63
Pos. 1: the graph represents the time and pressure in the two chambers of the cylinder during the positive and negative strokes and in the absence of the flow regulator. The distance t_1 on the time axis represents the time between the activation of the solenoid valve, the beginning of the pressurization of the positive chamber and the exhaust of the negative chamber.
The distanc t_2 represents the time of the stroke from the start of the exhaust of the negative chamber until the beginning of the cushioning phase of the piston against the end cap. By activating the solenoid valve, the pressure in the positive chamber increases, while the pressure in the negative chamber decreases. There is no movement since the pressure has not yet reached a value such as to generate a force capable of overcoming the load and the resistance of the exhausting air. (time t_1)
As soon as the movement of the piston starts the volume of the positive chamber increases, the pressure is slightly reduced then stabilizes since the flow rate of the valve is adapted to this constant volume change. (time t_2)
The piston comes in contact with the cushion seal of the cylinder, the variation in volume is now smaller and therefore the pressure tends to rise again. The piston stops at the end cap, the pressure stabilizes.
Pos. 2: in this case a flow regulator is mounted on the negative chamber, the times t_1 and t_2 increase.
The pressure in the negative chamber is not discharged with the same speed as shown in Pos. **1** as the flow regulator has a reduced passage. Pressure is created in the negative chamber, which opposes the thrust of the piston, therefore the speed decreases.

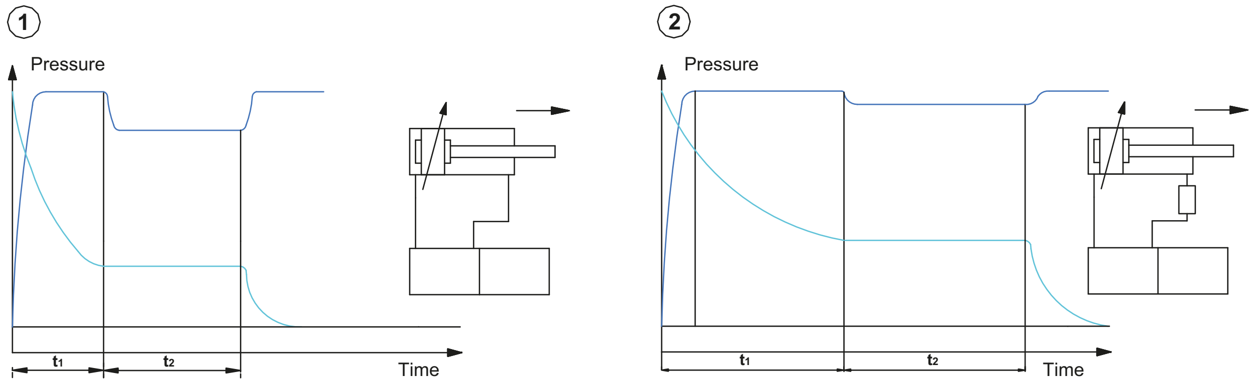


Fig. 63

Figure 64
Pos. 1: we have a double acting cylinder with adjustable speed in both directions. In the positive stroke the flow freely crosses the undirectional valve inside the regulator providing the highest flow rate. In the negative chamber the unidirectional valve forces the flow to pass through the adjustment screw.
Pos. 2: flow regulators can also be used for other functions, for example the return of a pneumatically operated valve can be delayed. The valve is activated immediately with the arrival of the pneumatic pilot signal, during the return phase (when the pilot signal disappears), the reduced cross section delays the exhaust, maintaining pressure on the pilot piston for a slightly longer duration.
Pos. 3: the volume/capacity positioned between the flow regulator and the pilot signal of the valve allows for this delay to be increased.
Pos. 4: mounting the flow regulator in the opposite way results in a delay in the piloting phase of the valve, the return is fast as the flow is free to exhaust.

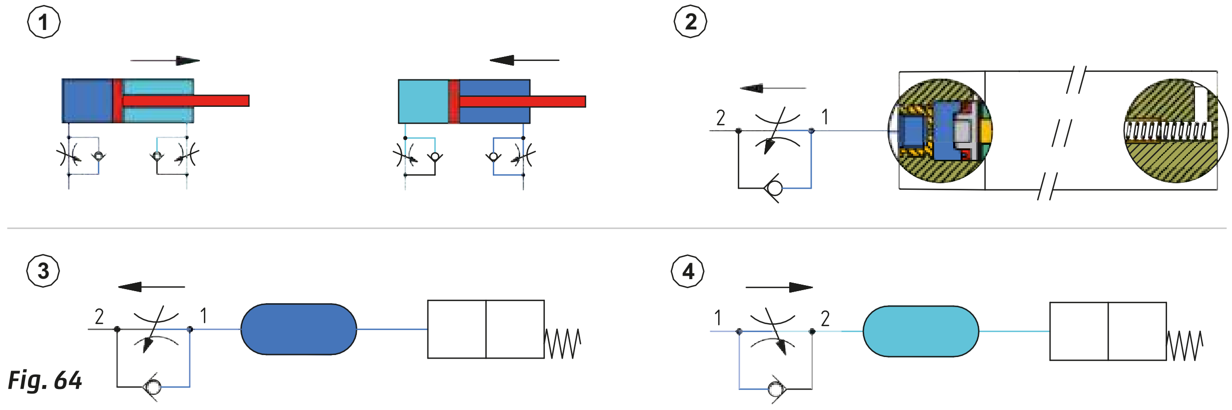


Fig. 64

Part 3
These valves enable the "control" of the speed of the piston rod/piston movement in the pneumatic cylinders, by the nears of the manual flow regulation device.

Figure 65
The information provided in this chapter serves to assist in selecting the size of the flow control valve and therefore calculate the performance of the cylinder connected to this device. Please refer to the graphs included in the catalogues that illustrate the nominal flow rate in relation to the number of turns of the adjusting screw.

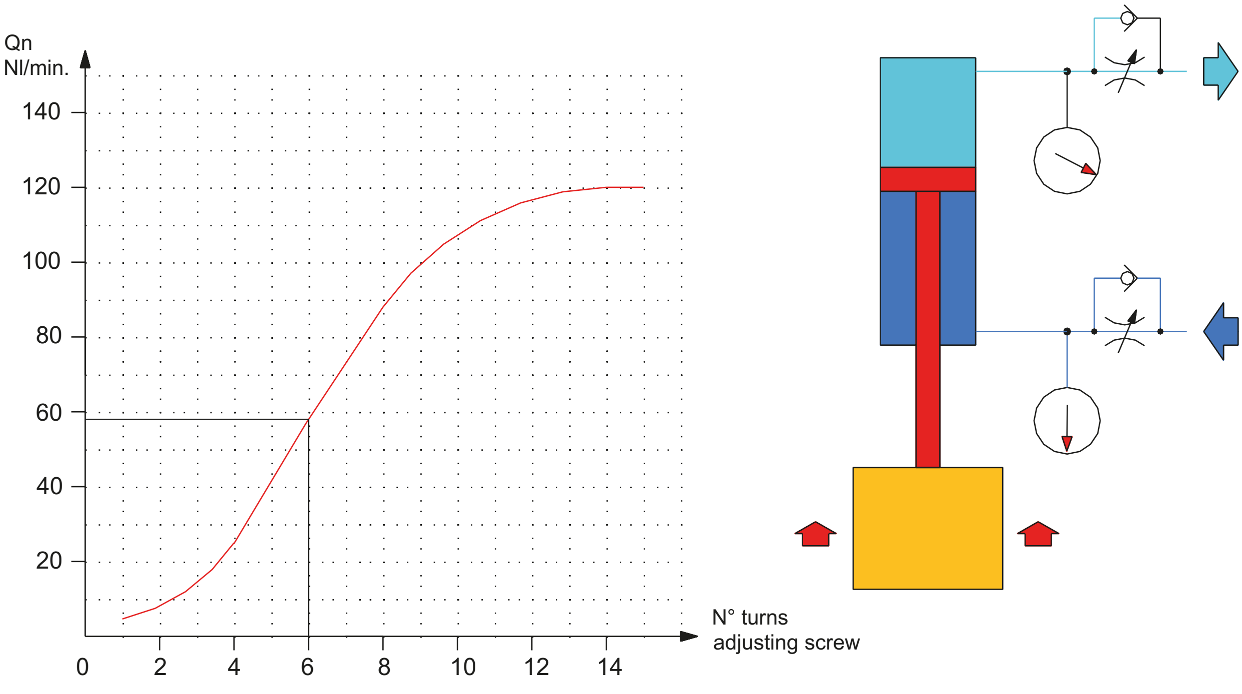


Fig. 65

Example: we have a cylinder of diameter 63 *mm*; stroke length 400 *mm*, with the piston rod pointing downwards. A load is applied on the piston rod. On the cylinder, two flow regulators are connected.

When lifting the load, the compressed air present in the positive chamber of the cylinder is exhausted, the value of the load applied to the rod remains unchanged throughout the stroke. Let's assume that during the movement the pressure value in the exhausting chamber is 3 *bar* and the flow regulator valve is open at 6 turns.

Calculation of the volume in the exhaust chamber V_s

$$V_s = (\pi * \pi * 3{,}14) * \text{Stroke}$$

$$V_s = (31{,}5 * 31{,}5 * 3{,}14) * 400 \qquad V_s = 3115 * 400 \qquad V_s = 1.246.266\ mm^3 \qquad V_s \cong \mathbf{1{,}25\ dm^3}$$

Considering that the exhaust pressure P has a value of 3 *bar* the volume V_3 becomes:

$$V_3 = V_s * (P + 1) \qquad V_3 = 1{,}25 * (3 + 1) \qquad V_3 = \mathbf{5\ Nl}$$

This is the amount of air, which is exhausted into the atmosphere once it passes the flow regulator. The capacity of the flow regulators is defined as nominal flow Q_n, calculated with 6 *bar* at the inlet and $\Delta p = 1$.
As discussed in previous chapters, it is possible to calculate the flow of free air at a certain pressure given the nominal flow rate Q_n.

This hypothetical regulator has a value Q_n of just under 60 *Nl/min*. Using the formulas already known we obtain the flow rate value at a pressure of 3 *bar*.

Calculation of the conductance C:

$$C = \frac{Q_n}{4{,}6} \qquad C = \frac{60}{4{,}6} \qquad C = \mathbf{13\ Nl / min * bar}$$

Calculation of flow at 3 *bar*:

$$C = \frac{Q}{(P_{rel} + P_{atm})} \qquad Q = C * (P_{rel} + P_{ass}) \qquad Q_3 = 13 * (3 + 1) \qquad Q_3 = \mathbf{52\ Nl / min} \qquad Q_3 = \mathbf{0{,}86\ Nl / sec}$$

Dividing the quantity of air enclosed within the exhaust chamber with the value of flow exiting the regulator it is possible to obtain the required time for the stroke of the cylinder:

$$t = \frac{V_3}{Q_3} \qquad t = \frac{5}{0{,}86} \qquad t \cong \mathbf{5{,}8\ sec}$$

Adjusting the number of revolutions of the regulator changes the value of the exhaust flow thereby increasing or reducing the speed of the cylinder.

The movement speed, i.e. the time required to complete the cylinder stroke does not change even if the pressure changes.

Suppose that the previous cylinder completes the negative stroke without a load, and in the positive chamber there is a higher-pressure value, for example 6 *bar*. The quantity of air to be discharged is greater than in the previous case as is the quantity of air that is released into the atmosphere.

Calculation of the volume of the exhaust chamber V_6:

$$V_6 = V_S * (P + 1) \qquad V_6 = 1{,}25 * (6 + 1) \qquad V_6 = \mathbf{8{,}75\ Nl}$$

We leave the number of revolutions of the adjustment screw (6) unchanged and we calculate the flow of free air at a value of 6 *bar*:

$$Q = C * (P_{rel} + P_{ass}) \qquad Q_6 = 13 * (6 + 1) \qquad Q_6 = \mathbf{91\ Nl / min} \qquad Q_6 = \mathbf{1{,}51\ Nl / sec}$$

Dividing the quantity of air enclosed within the exhaust chamber with the value of flow exiting the regulator it is possible to obtain the required time for the stroke of the cylinder.

$$t = \frac{V_6}{Q_6} \qquad t = \frac{8{,}75}{1{,}51} \qquad t \cong \mathbf{5{,}8\ sec}$$

The change in pressure does not influence the time of a cycle.

Usage of valves with vacuum

Not all of the valves can be used with a vacuum, several parameters must be taken into consideration such as: the internal construction, the type of switching, the type of seals used and other factors.

We examine mini poppet valves as an example:

Figure 66
Pos. A: in a mini poppet valve, the presence of pressure at inlet 1 pushes the seal upwards towards the upper orifice. In this case, we have an NC valve.
Pos. B: on the same valve the presence of a vacuum at inlet 1 drags the seal downwards towards the lower orifice, the valve does not respond to any manoeuvre on the push button. Assuming there is a vacuum present at outlet 2, we have the same situation as in Pos **A**, whereby the seal on the inlet is drawn upwards and there is continuous passage through the exhaust 3, also in this case the valve will not respond to any manoeuvre on the push button.
Pos. C: a spool valve may be used, which would depend on the geometry of the internal seals. Assuming we apply a vacuum at inlet 1, and the valve is in the NO position, the vacuum is usable at connection 2, exhaust 3 is closed. Activating the spool closes the vacuum port 1 and connects atmospheric pressure to the outlet 2.
Assuming we apply a vacuum at exhaust 3, and the valve is in the NO position, the vacuum does not pass and outlet 2 is at atmospheric pressure due to inlet 1.
By activating the spool the vacuum opens and closes communication with the atmospheric pressure.

There are generally no problems encountered with vacuum on spool valves with mechanical or manual operation; on electrically operated valves, external piloting is necessary. In the case of directly operated solenoid valves, generally no problems are encountered.

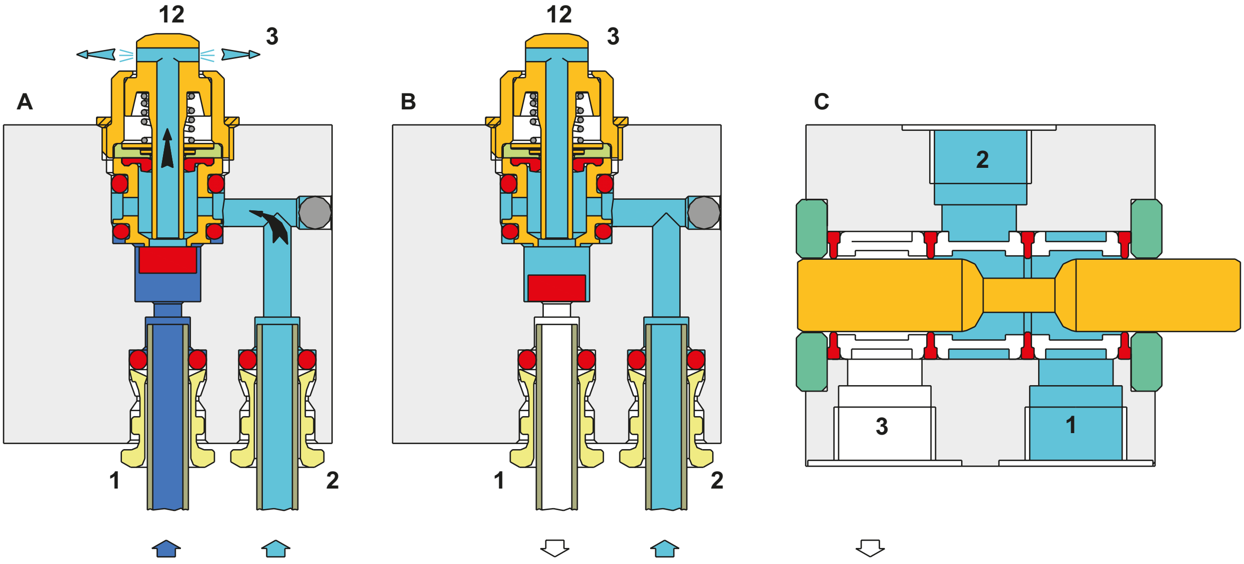


Fig. 66

Pressure switches

To enable a system to operate properly, the pressure needs to reach a value suitable for the requirements, and only in this state the cycle may begin. Pressure switches are thereby employed to ensure this value remains within the allowed range.

The pressure switch is a component that is connected to the source of the compressed air, and uses that pressure to commutate an electrical switch.

The most common are:
- with **Normally Closed contact (NC)**
- with **Normally Open contact (NO)**
- with **Exchange contact (NC** and **NO)**

The pressure switch can be regulated to adjust the switching point of the switch to the necessary pressure value. The adjustment is made by means of a regulation screw, which, by placing a load on a spring, acts on a diaphragm, and so opposes the thrust force from the air.

Figure 67
NC Model: in the absence of pressure the switching elements are in contact with each other closing the electric circuit so that the signal is present. Upon applying pressure, the switching elements separate from each other and the electric circuit is interrupted.

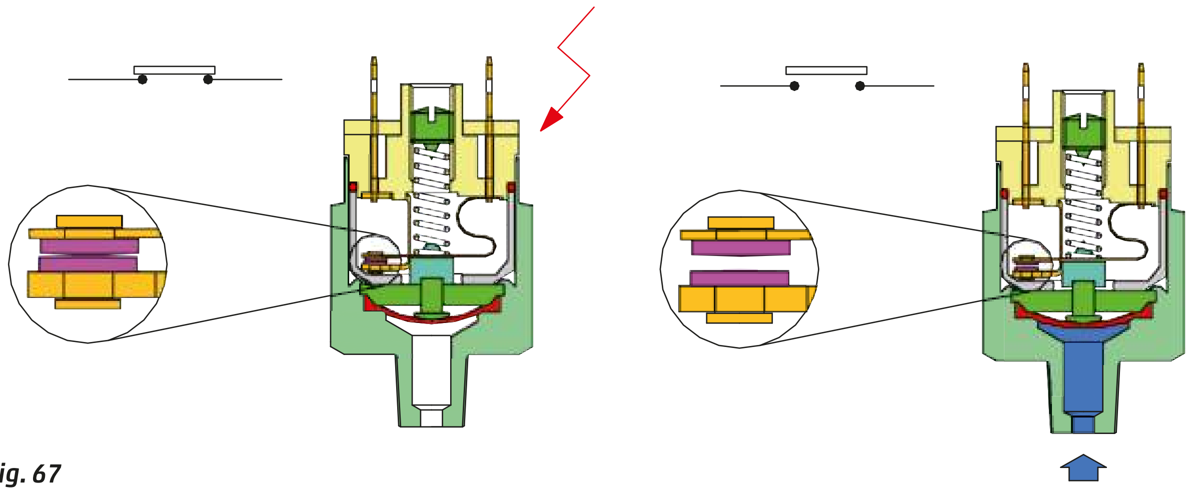


Fig. 67

Figure 68
NO Model: in the absence of pressure on the diaphragm, the switching elements have no contact with each other and the electric circuit is interrupted. In applying pressure on the diaphragm, the electrical contact closes the circuit, enabling the signal.

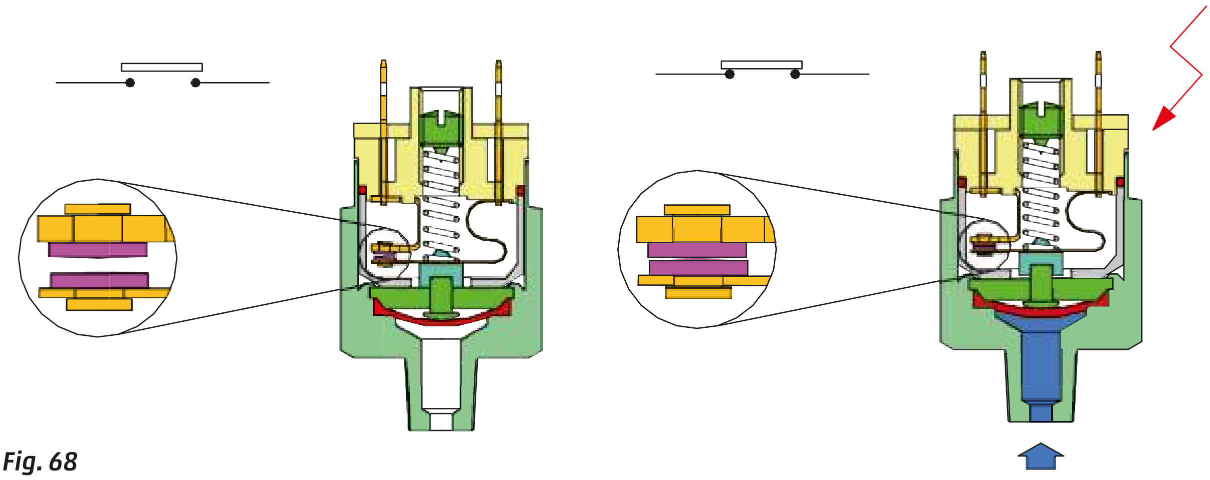


Fig. 68

The **Exchange contact Model** is similar to previous models, the only difference is that this type of switch is equipped with both **NC** and **NO** contact.

CHAPTER 5

CIRCUIT TECHNIQUE

Pneumatic symbols

The drawings demonstrating the construction and functional characteristics of the components described in the previous chapter also illustrate the relevant symbols. The symbols are listed here alongside a brief description.

Figure 1
Air preparation

Pos. 1:
A: **Filter** - generic representation
B: **Filter** - with manual condensate drain
C: **Filter** - with automatic condensate drain
Pos. 2:
A: **Pressure regulator** - with relieving; with discharge of the excess pressure, (relieving). The line with two arrows indicates the direction of the main flow towards the point of use, and the direction of discharge of the excess pressure.
B: **Pressure regulator** - without relieving; without discharge of the excess pressure.
(Note: the small triangle on the upper left is omitted)
Pos. 3: Lubricator - generic representation
Pos. 4: Soft start valve - provides a gradual regulated flow to the compressed air system.
Upon reaching approx. 50% of the inlet pressure, the valve fully opens the passage. The arrow indicates the direction of flow.
Pos. 5:
A: **F.R.L**, group, detailed symbol
B: **F.R.L**, group, simplified symbol

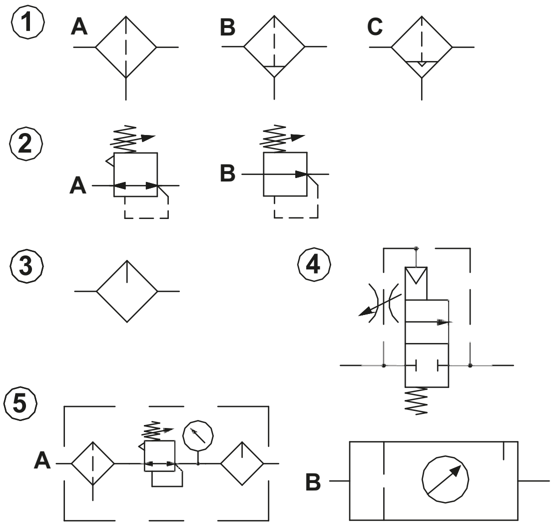


Fig. 1

Figure 2
Cylinders

A: **Single-acting cylinder - non magnetic** with mechanical spring return, fixed mechanical cushioning, negative stroke
B: **Single-acting cylinder - magnetic** with mechanical spring return, fixed mechanical cushioning, negative stroke
C: **Double-acting cylinder, non magnetic**
D: **Double-acting cylinder, non magnetic** with fixed mechanical cushioning on both sides of the piston
E: **Double-acting cylinder, non magnetic** with adjustable pneumatic cushioning in both directions
F: **Double-acting cylinder, magnetic** with fixed mechanical cushioning in both directions
G: **Double-acting cylinder, magnetic** with adjustable pneumatic cushioning positive stroke and fixed mechanical cushioning negative stroke
H: **Double-acting cylinder, magnetic** with adjustable pneumatic cushioning in both directions

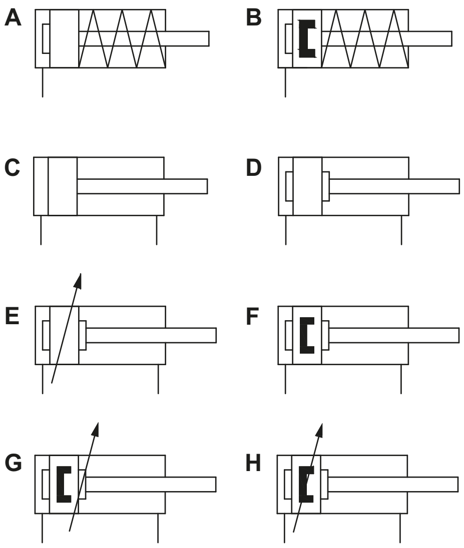


Fig. 2

Figure 3
Directional control valves

A: **2/2-way monostable** closed in rest position (2/2-way NC)
B: **2/2-way monostable** open in rest position (2/2-way NO)
C: **3/2-way monostable** closed in rest position (3/2-way NC)
D: **3/2-way monostable** open in rest position (3/2-way NO)
E: **5/2-way**
F: **5/3-way** valves with closed centers (5/3-way CC)
G: **5/3-way** with open centers (5/3-way CO)
H: **5/3-way** with pressure centres (5/3-way CP)

The direction of the arrow indicates the direction of flow, some symbols must be completed with the addition of an operation and return device.

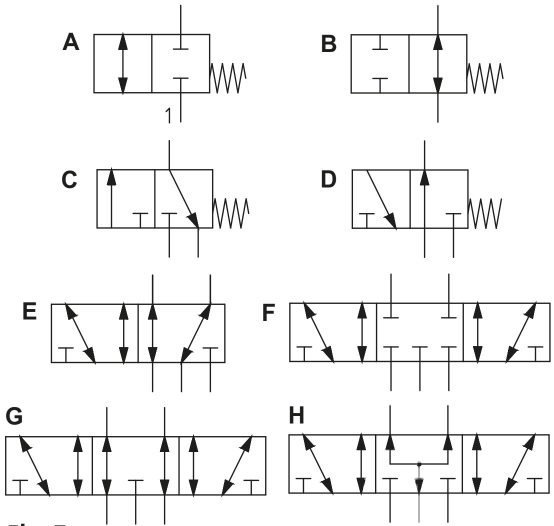


Fig. 3

Figure 4
Logic valves
A: function **OR** selector valve
B: function **AND** 2 input valve
C: function **NOT** inverter valve
D: function **YES** amplifier valve

Figure 5
Pos. 1:
Isolation interception valves
A: non-return valve
B: quick exhaust valve
Pos. 2:
A: unidirectional flow regulator
B: bidirectional flow regulator

Figure 6
Operating devices
A: manual lever
B: manual lever with stable position
C: pedal
D: manual with (mushroom) push button
E: manual with push and pull button
F: pneumatic pilot
G: direct electrical - pneumatic pilot
(for solenoid valves)
H: electro-pneumatic (solenoid pilot)
with bistable manual override
I: mechanical with bidirectional roller lever
M: mechanical with unidirectional roller lever
N: pneumatic spring return
P: mechanical spring return

Figure 7
Additional symbols
A: pressure source
B: pressure line
C: control or pilot line
D: fixed connections
E: passing lines
F: capacity/reservoir
G: closed port
H: pressure gauge

Some symbols are to be completed with the symbols for the actuation and repositioning.

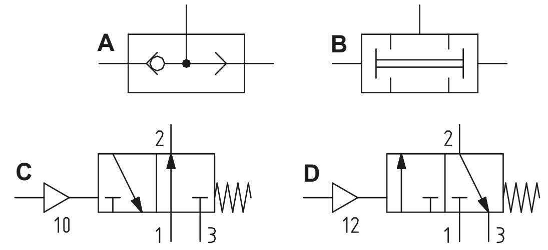


Fig. 4

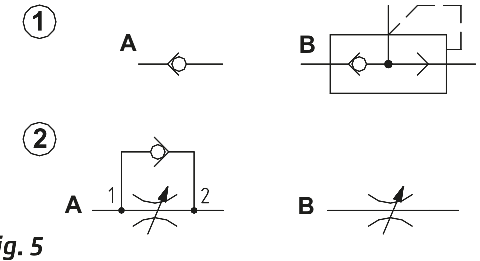


Fig. 5

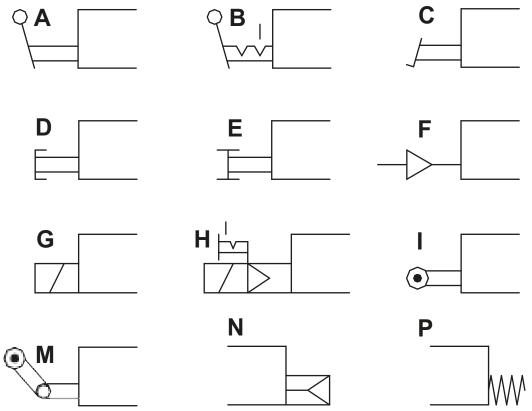


Fig. 6

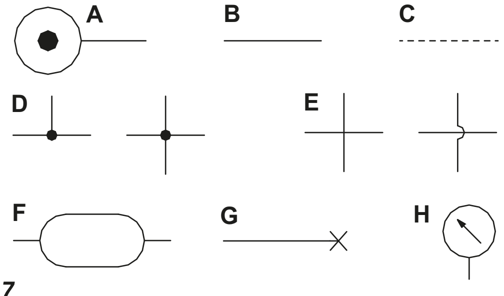


Fig. 7

Rules for designing circuits

Any circuit, regardless of whether it is electric or pneumatic, comprises a set of conventional lines and symbols representing their respective functions, connections, and state of command at the end of cycle position. In the previous sections we illustrated the symbols of the components. Below we demonstrate how to draw and join them together to create a circuit.

Figure 8
Pos. 1:
A: the pressure source is represented by a circle with a dot in the centre. It can be indicated on any component that can receive the pressure source. The connection between the two parts is achieved via a tube.
B: the pressure source can be illustrated as a single entity, then distributed to the various elements.
Pos. 2: a continuous solid line is used to identify "working" or "power" tubes.
Pos. 3: it is preferable to avoid intersecting connecting lines in the drawings wherever possible. Where it is not possible, it is advisable to interrupt one of the two lines and form a small arc to indicate the tubes overlapping. Connections are best highlighted with a small clearly visible dot.

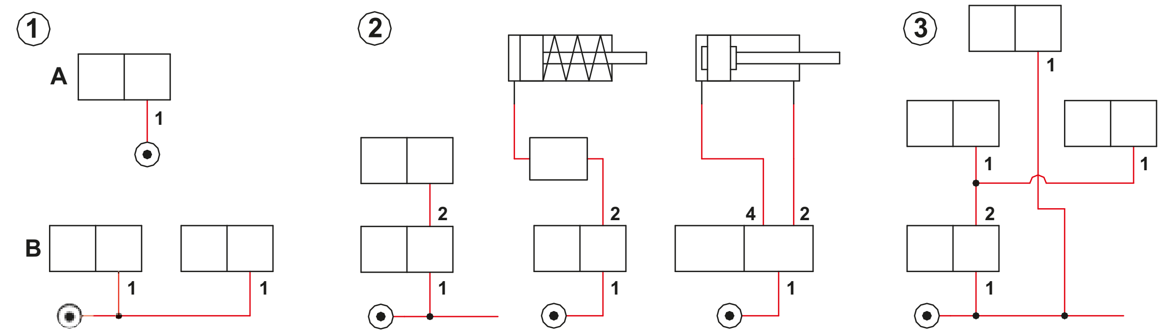


Fig. 8

With a dashed line, we represent tubes which:

Figure 9
Pos. 1: determines the piloting of pneumatic valves
Pos. 2: indicates whether the servo pilot of a solenoid valve is external
Pos. 3: represents the input and output connections of the signal handling valves
Pos. 4: indicates the inlet and outlet of the functional valves
Pos. 5: in some cases the pipes must be represented in two ways at the outlet of a distribution valve; with a dashed line for switching a pneumatic operated valve, and a continuous line for feeding another valve.

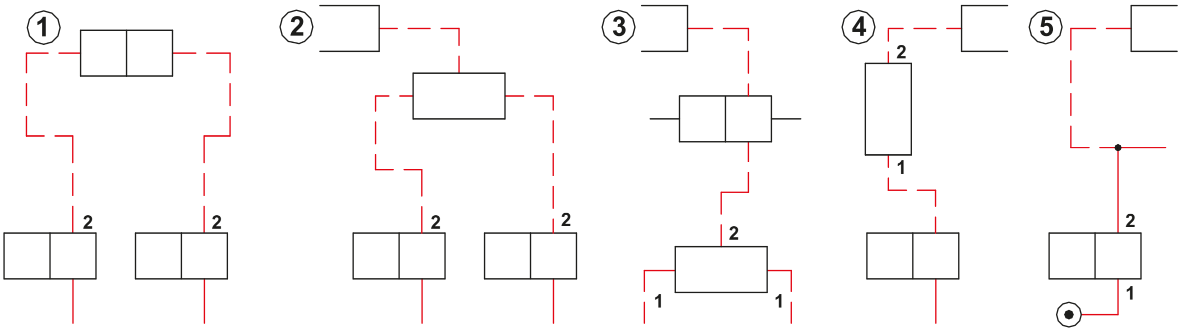


Fig. 9

The continuous line is generally the most represented.

The circuit drawing must represent all of the components in the position they assume when the machine/equipment is at the end of the cycle.

Figure 10
The cylinders are represented by a rectangle, the piston rod/piston is located inside this rectangle. The position of the piston rod indicates whether the rod is retracted or not.

Fig. 10

The valves are represented by two small adjacent squares, which define the positions the valve can assume. Arrows positioned inside the squares indicate the direction of the flow of compressed air.
In the non-operated position, pneumatic connections and their relative identification numbers are illustrated in the small square adjacent to the spring. In the operated position the external connections and the connections are illustrated in the small square located next to the operator symbol.

Figure 11
Pos. 1: 3/2-way NC valve mechanically operated with mechanical spring return.
Pos. 2: 3/2-way NO valve mechanically operated with mechanical spring return.
Pos. 3: 3/2-way NC valve pneumatically operated with mechanical spring return. The presence of the pilot signal is not directly detectable (unlike the previous cases). The position of the external connection and valve port numbers will indicate the presence/absence of the pilot signal.
Pos. 4: 5/2-way valve bistable pneumatically operated. The pilot ports (control signals) are positioned on the short ends of the valve. Either outlet 2 or outlet 4 is always connected to inlet 1. The active position is indicated by the square in which the external connections and port numbers are located.

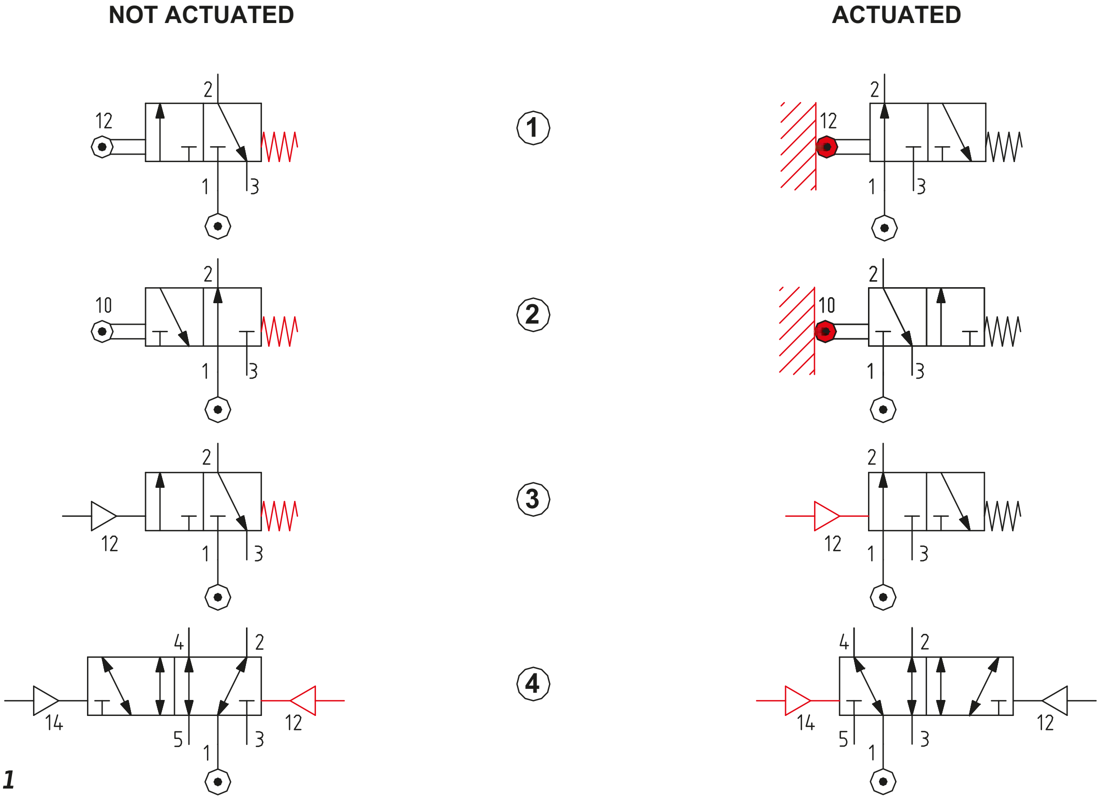


Fig. 11

Elementary circuits

The term elementary circuit refers to “basic” circuits such as those for the control of a single cylinder.

Control of a single-acting cylinder

When pressurizing only one chamber of a cylinder, a 3/2-way **(3-ways 2-position)** valve is used. The selection of the NC or NO version of this valve depends on the selected position of the cylinder at the beginning of the cycle.

Figure 12
Pos. 1: with an NC valve, there is no compressed air exiting outlet 2 (while at rest position), the piston is in the negative or retracted position due to the effect of the mechanical spring.
Pos. 2: the compressed air present at inlet 1 cannot pass because the valve is NC. Inlet 1 is closed and outlet 2 is connected to exhaust port 3 (valve at rest position).
Pos. 3: when the operator presses and holds down the push button, the compressed air passes through the valve from inlet 1 to outlet 2 (actuated valve). This air arrives to the cylinder pressurizing the positive chamber.
The piston moves forward to its extended position.
Pos. 4: when the button is released, the valve returns to its rest position, the inlet 1 closes and outlet 2 connects with exhaust 3 in order to allow the compressed air in the cylinder chamber to exhaust into the atmosphere, allowing the piston to return to its original position with the help of its spring.

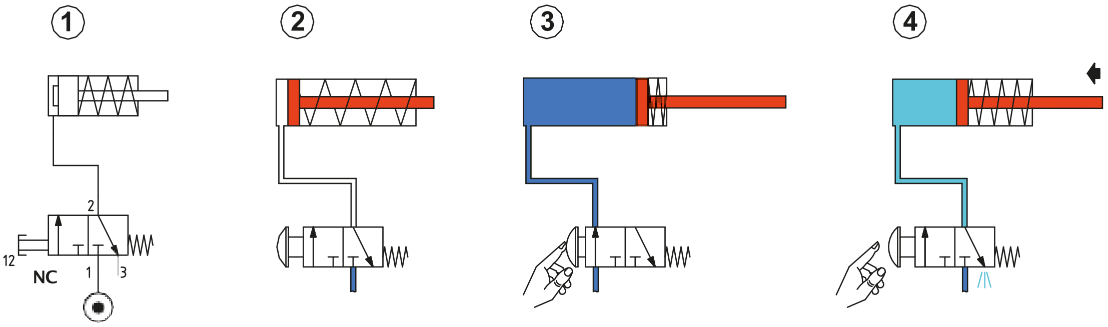


Fig. 12

Figure 13
Pos. 1: with an NO valve, compressed air is exiting from outlet 2 (while at rest position), the piston rod/piston reaches the positive end position due to the thrust of the compressed air which compresses the spring inside the cylinder.
Pos. 2: the compressed air passes through the valve from inlet 1 to outlet 2 (valve at rest position). This air reaches the cylinder and pressurizes the positive chamber, moving the piston rod/piston forward to its extended position.
Pos. 3: when the operator presses and holds down the push button, the passage between inlet 1 and outlet 2 is interrupted. The compressed air present in the cylinder chamber passes outlet 2 and discharges through exhaust 3. The piston rod/piston retreats due to the effect of the mechanical spring.
Pos. 4: when the push button is released, the valve returns to its rest position, inlet 1 opens allowing the compressed air through outlet 2, enabling the return of the piston rod/piston to the positive end position.

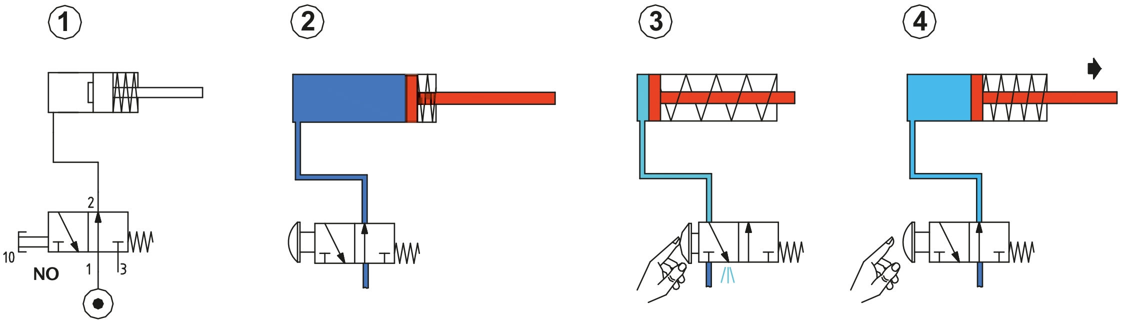


Fig. 13

Control of a double-acting cylinder

Double-acting cylinders (DA) require air to flow in two directions to achieve both positive and negative strokes. For this reason, the distribution valve must have two independent outlets, i.e., a 5/2-way **(5-ways 2 position)** valve.

Figure 14
Monostable valve, directly operated
Pos. 1: the 5/2-way monostable valve in rest position has outlet 2 under pressure. The position of the piston rod/piston of the double-acting cylinder, which is controlled by the valve, is dependent upon which chamber the active outlet 2 is connected to.
Pos. 2: the valve is at rest, the compressed air is connected to inlet 1 through outlet 2 and supplies the negative chamber of the cylinder, holding the piston rod/piston against the rear end cap.

Pos. 3: pressing and holding the push button opens the passage between inlet 1 and outlet 4, while outlet 2 connects to exhaust 3. The compressed air enables the movement of the piston rod/piston, which reaches the positive end position.
Pos. 4: when the push button is released, the valve returns to its rest position, resuming communication between inlet 1 and outlet 2, while outlet 4 is in communication with exhaust 5. The piston rod/piston returns to the initial position.

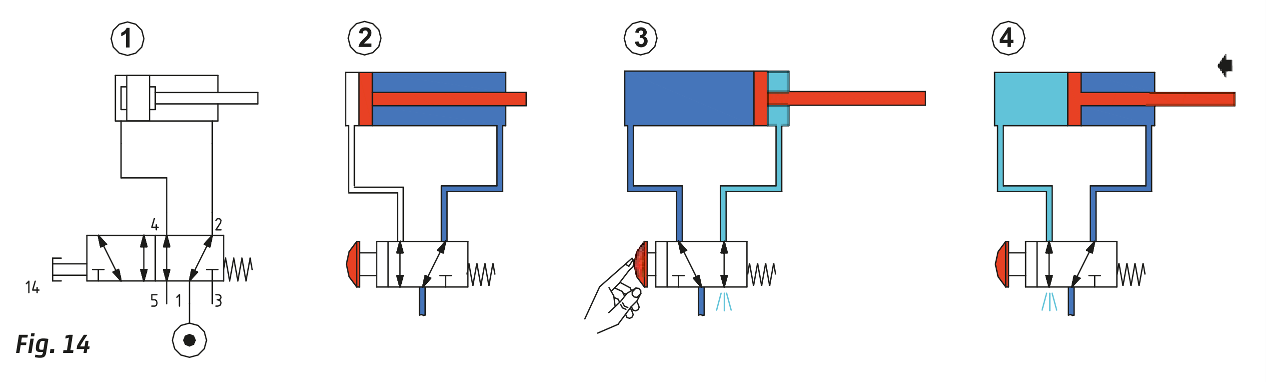


Fig. 14

Figure 15
Bistable valve, directly operated
Pos. 1: the bistable 5/2-way valve does not have a definite rest position and as a consequence, either outlet 2 or 4 may be active.
Pos. 2: with the lever in this position there is passage of compressed air between inlet 1 and outlet 2. The piston rod/piston reaches the positive end position.
Pos. 3: by moving the lever, inlet 1 is put in communication with outlet 4 while outlet 2 is discharging through exhaust port 3. The piston rod/piston moves until it reaches the negative end position.
Pos. 4: through repositioning the lever, inlet 1 is once again in communication with outlet 2 while outlet 4 is exhausted through the exhaust port 5. The rod/piston rod reaches the positive end position.

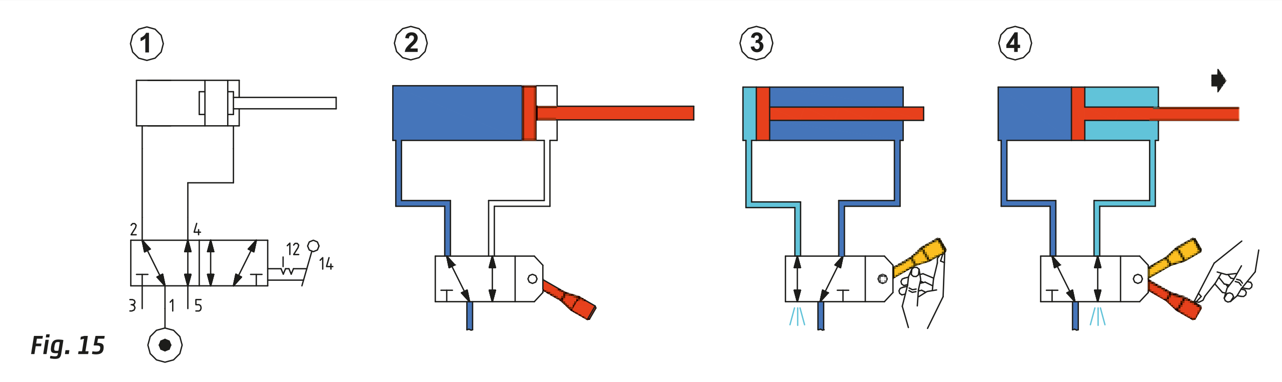


Fig. 15

These introductory circuit solutions are called **direct control** and represent the simplest way for controlling the movement of a cylinder. In this circuit there is only a single valve with a dual function: distribution and control.

It is not always convenient for the operator to directly operate a control valve, especially when located in close proximity to the actuator. In such situations, it is possible to use a pneumatically operated valve, commanded by a valve located in a safe or more accessible position as an alternative. In this case, the command is no longer **direct** (as in the previous chapters), but it is now **indirect** due to the presence of the second pilot valve. The dimensions of this valve and its connection ports can be quite small (as there is no need for a large flow rate). The actuation forces necessary for its activation (in the manual version) can be reduced, as a high flow rate is not necessary.

Figure 16
Monostable valve, indirectly operated
Pos. 1: the **pilot** valve is a 3/2-way monostable valve with mechanical spring return and manual operation (push button). The **main** valve is a 5/2-way monostable valve with mechanical spring return and pneumatically operated. Outlet 2 of the pilot valve is connected to the pilot port 14 of the main valve.
Pos. 2: in the absence of a pilot signal, the main valve is at rest, the compressed air connected to inlet 1 through outlet 2, pressurizing the negative cylinder chamber, keeping the piston rod/piston against the rear end cap.
Pos. 3: by pressing and holding the push button, the passage between inlet 1 and outlet 2 is opened that commands the main valve. The main valve switches, outlet 2 exhausts through the exhaust port 3 and inlet 1 is in communication with outlet 4. The compressed air enables the movement of the piston rod/piston, which reaches the positive end position. This condition is maintained as long as the operator depresses the push button on the pilot valve.

Figure 16
Pos. 4: as the button is released, the command signal is discharged through outlet 3 of the pilot valve. The main valve returns to rest position due to the effect of the spring, putting inlet 1 in communication with outlet 2. Outlet 4 is exhausted through the exhaust port 5. The piston rod/piston returns to its initial position.

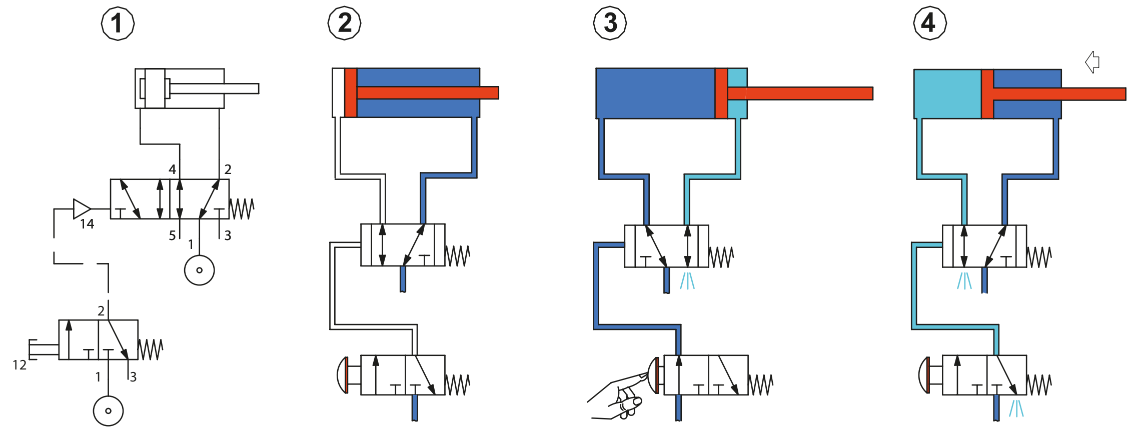


Fig. 16

Figure 17
Bistable valve, indirectly operated
Pos. 1: with this type of main valve, two pilot signals are required; a second pilot valve is added.
Pos. 2: the bistable 5/2-way valve does not have a definite rest position and as a consequence, either outlet 2 or 4 may be active. As none of the pilot valves are activated, in this case the main valve pressurizes the cylinder so that the piston rod/piston is in the negative end position.
Pos. 3: if the left push button is activated; the passage between inlet 1 and outlet 2 on the pilot valve is opened, pressurizing the pilot port 14 of the main valve. The main valve changes over so the outlet 2 is exhausted through the exhaust port 3, inlet 1 is in communication with outlet 4, pressurizing the positive chamber of the cylinder, the piston rod/piston reaches the positive end position. This condition is maintained even if the signal from the pilot valve is interrupted. Upon releasing the push button, outlet 2 of the pilot valve exhausts through the exhaust port 3.
Pos. 4: by activating the button on the right, the passage between inlet 1 and outlet 2 of the pilot valve is opened, pressurizing the pilot port 12 of the main valve. The main valve changes over, outlet 4 exhausts through the exhaust port 5, inlet 1 is in communication with outlet 2, pressurizing the negative chamber of the cylinder, the piston rod/piston reaches the negative end position. This condition is maintained even if the signal from the pilot valve is interrupted.

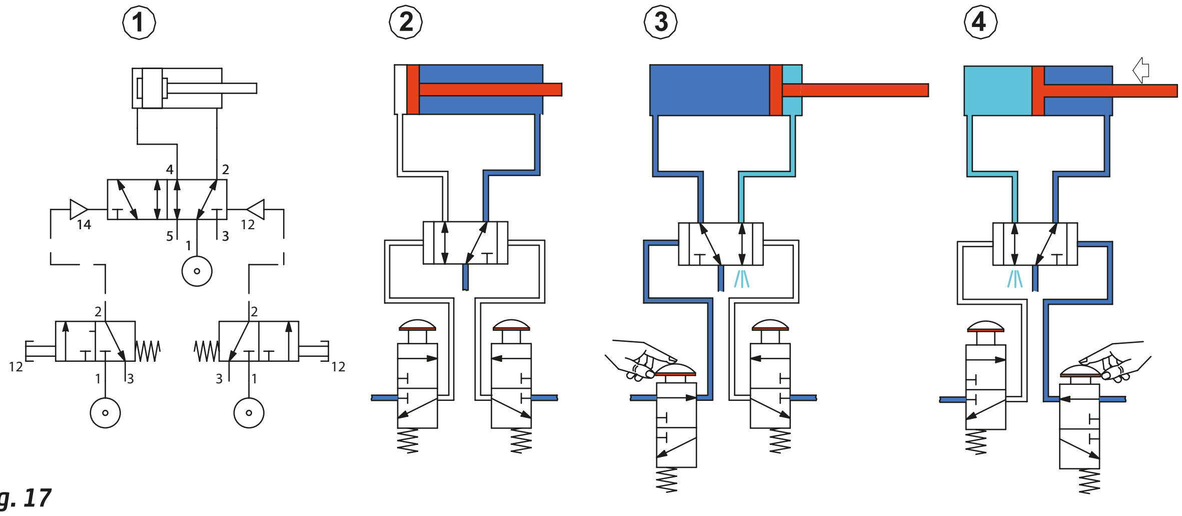


Fig. 17

If the button on the right were to remain activated while the button on the left was activated, the main valve would receive two pilot signals but there would be no response, as the valve would remain in the position determined by the first pilot signal received.

Single or semi-automatic cycle

In circuits, the actuators move at different times according to a defined logical sequence. The various phases, which comprise the sequence, are dependent upon "confirmation" from the "limit switches". These are valves with mechanical activation devices that are directly operated by the actuators or by mechanical components connected to them. Because they can be placed anywhere along the stroke, they can be activated at the required moment.

The machine operator limits his actions to "**Start**" and "**Stop**" controls.

To simplify, we use a single cylinder producing a "**single or semi automatic cycle**" that is to say; for every manual operation of the Start command, the cylinder performs only one cycle.

Figure 18

Pos. 1: the **Start** command is supplied via a manual 3/2-way NC valve with mechanical spring return. The **main valve** is a pneumatically operated bistable 5/2-way valve. The repositioning command is supplied by a mechanically operated 3/2-way NC valve with spring return.
Pos. 2: the bistable 5/2-way valve does not have a definite rest position and either outlet (2 or 4) may be active. In this specific case, as neither the start button nor the limit switch are actuated, the main valve feeds the cylinder therefore the piston rod/piston is in the negative end position.
Pos. 3: as the Start button is activated, the main valve receives the pilot signal 14, and the passage between inlet 1 and outlet 4 is opened, outlet 2 exhausts through exhaust port 3. The compressed air feeds the positive chamber of the cylinder, moving the piston rod/piston until it reaches the positive end position.
Pos. 4: when arriving at the positive end position, indicated by the vertical line, the piston rod actuates the limit switch through the mechanical actuation device, whereby the passage between inlet 1 and outlet 2 is opened, delivering the pilot signal 12 to the main valve in order for the signal to proceed, there can be no signal coming from the Start button.
Pos. 5: Upon releasing the Start button, the piston rod/piston detaches from the end position, the limit switch closes the passage between inlet 1 and outlet 2 and releases the pilot signal to the main valve through connection 3.

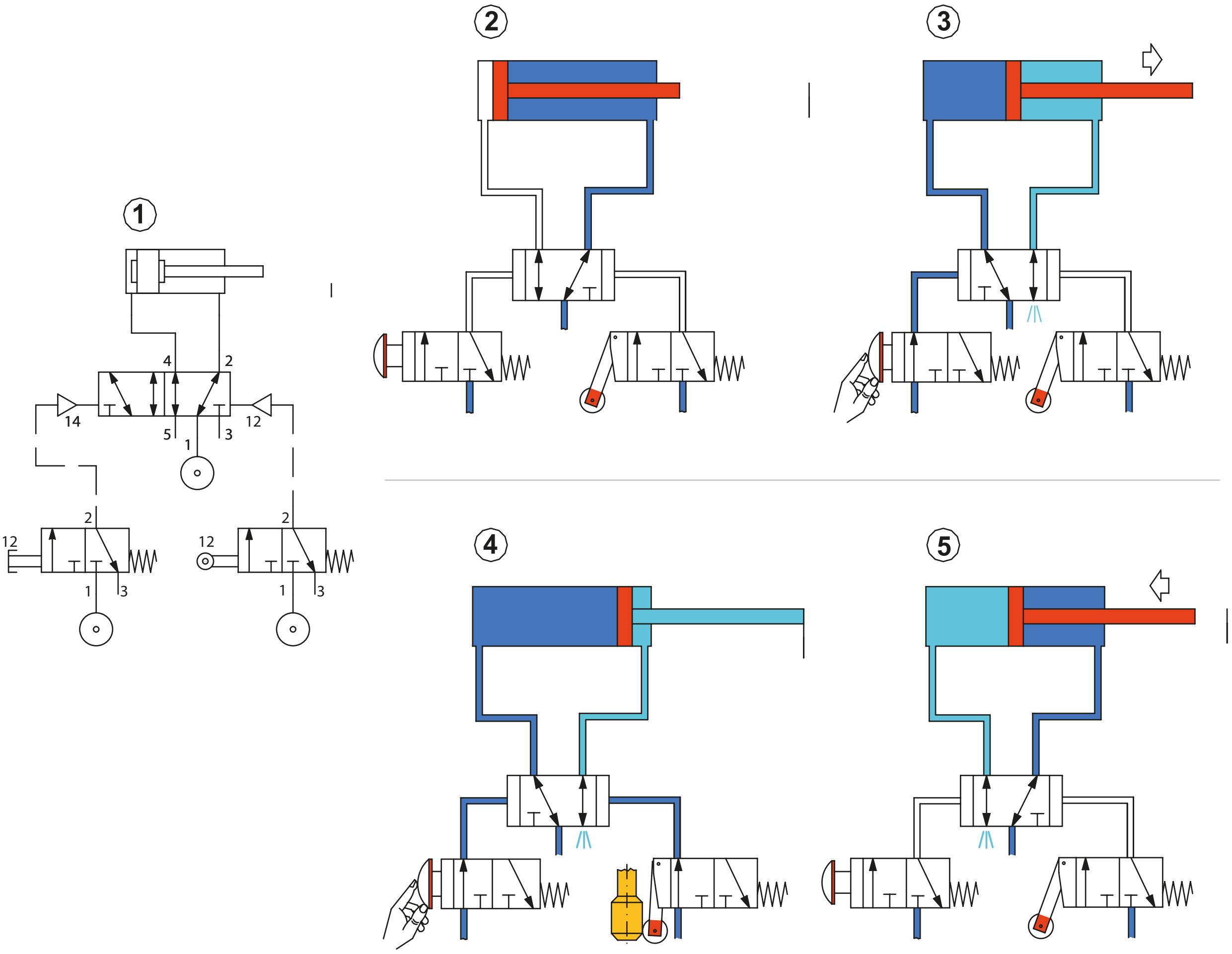


Fig. 18

The repetition of the cycle is possible if the start valve is re- activated.

Continuous or automatic cycle

In the previous circuit, it was possible to achieve the automatic return of the cylinder using a mechanical valve (limit switch) at the end of the positive stroke position. For the cycle to continue automatically, another mechanical valve (limit switch) would need to be inserted, together with an additional "Start" function, as the Start/End Cycle command is always given by the operator.

In this example (as in the previous) we will use only one cylinder completing a **continuous or automatic cycle**. This implies that the cycle is repeated automatically, providing the operator doesn't switch the manually operated valve to its "End Cycle" position.

Figure 19

Pos. 1: in contrast to the previous single or semi-automatic cycle, the "start" button is replaced by a manually operated bistable 3/2-way valve (**I.C-start cycle**) representing the functions "Start/End Cycle", whose air supply is determined by the state of the limit switch at the negative end position. The **main** valve is a pneumatically operated bistable 5/2-way valve.

Pos. 2: the compressed air is present at the inlet of all of the valves; it passes through the 5/2-way valve, which feeds the negative chamber of the cylinder. The negative limit switch (located at the negative end position), being activated, feeds the **I.C.** valve, which in this state does not permit the start of the cycle.

Pos. 3: by moving the lever of the **I.C.** valve there is passage of compressed air towards the main valve which is commanded now receiving the pilot signal 14, allowing the movement of the piston rod/piston towards the positive end position. The piston rod/piston via its movement, releases the negative limit switch closing the passage of compressed air, permitting the exhaust of the pilot signal. The operation of the **I.C.** valve is not needed as it is bistable, and therefore its position is maintained.

Pos. 4: the piston rod/piston reaches the positive limit switch which is thereby activated, and through its outlet 2, feeds the pilot signal 12 to the main valve which changes over and inverts the direction of air in the cylinder chambers. The piston rod/piston begins returning towards the negative end position. The positive limit switch is released through the movement of the piston rod/piston.

Pos. 5: the piston rod/piston reaches the negative end position, activating the negative limit switch. The outlet 2 of this switch feeds the **I.C.** valve. The cycle will continue to repeat automatically, assuming the operator does not intervene.

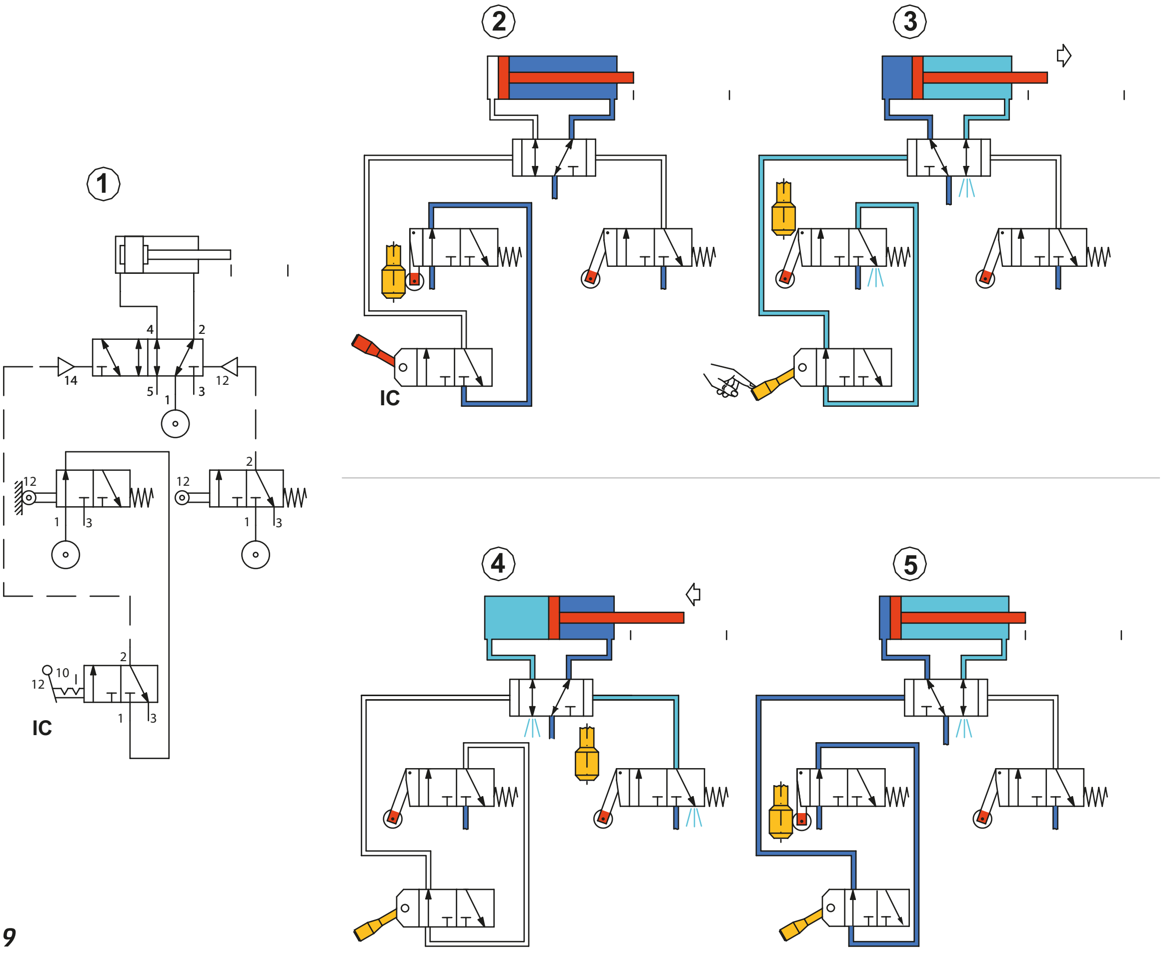


Fig. 19

If the lever of the **I.C.** valve is repositioned, regardless of its position, the piston rod/piston will continue its movement until the completion of the cycle, and then stops.

Elementary circuits

In previous circuits, we used **5-way/2-positions** as main valves and **3-way/2-positions** as limit switches (pilot valves). In this section we use the **5-way/3-position** valves, which can have three positions: **Closed Centers (CC)**, **Open Centres (OC)**, and **Pressure Centres (PC)**.

Figure 20
Closed Centers(CC)
In this state all connections on the valve are intercepted and closed. By blocking both the incoming and the outgoing compressed air from the cylinder, it remains trapped inside and moves the piston rod/piston until there is an equilibrium of pressure within the two chambers. At this point, the movement stops. This condition is to be considered neither stable nor safe. Any leak from the seals, either from the piston, the connection fittings, the valve or the breakage of a connection tube, would create a pressure difference in the chambers of the cylinder and the consequent movement of the piston rod/piston.

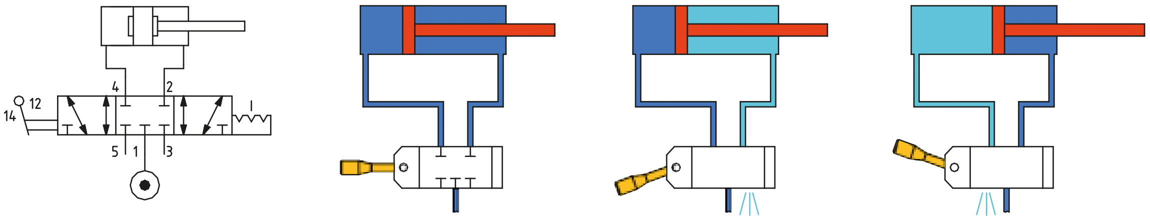


Fig. 20

Figure 21
Open Centers (OC)
Inlet 1 of the compressed air is closed; the two outlets 2 and 4 are connected to the cylinder chambers, open towards the exhaust ports 3 and 5. There is atmospheric pressure in the cylinder chambers, and as a consequence, the piston rod/piston is free to move. Note: once the piston resumes its movement after it has stopped in the OC position of the valve, it is no longer controllable as there is no compressed air in the exhaust chamber. An eventual flow regulation valve would not function properly.

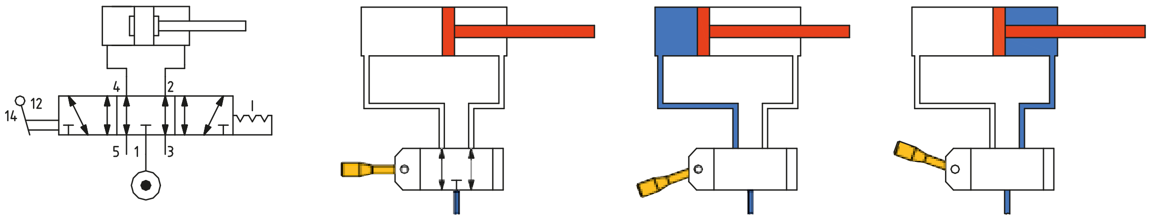


Fig. 21

Figure 22
Pressure Centers (PC)
The two cylinder chambers are pressurized, the different thrust area on the piston of the cylinder due to the presence of the rod, gives a resulting force whereby the piston rod/piston moves towards the positive end position. In this case the value of the applied load is also relevant, if it is greater than the resultant (force) the piston rod/piston will remain stationary. This function can be applied for example in the movement of a door which can be opened manually with a reduced force in the case of an emergency.

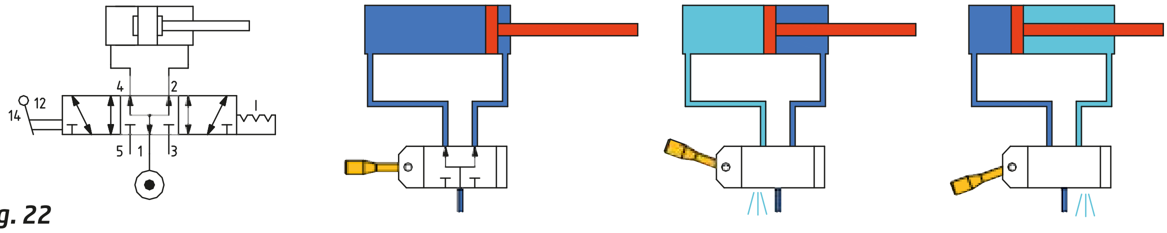


Fig. 22

The electrically and pneumatically operated 3 position valves are monostable, the third position is obtained in the absence of apilot signal due to the effect of return springs. Manual valves can be monostable or bistable, their positions are determined by the operator.

Literal and graphical representation of the movement of cylinders

The cycle of a cylinder is the movement of the piston rod/piston in both directions. The positive (+) and negative (-) strokes of the piston can be shown in two different forms:

Literal: this form uses the identifying letter of cylinder and the direction of the piston stroke E.g. **A+ /A-** or **B- /B+**. The slashed line indicates there are two separate phases with one piston movement in each Phase.
Graphical: all the letters are transcribed on lines. The phases of the cycle are indicated within the columns. The type of action of the cylinder relevant to the Phase is illustrated in the square formed by the intersection between the row and column. The number of the phase is indicated in the upper part of the diagram.

Figure 23
Pos. 1: the cycle of the cylinder **A** (**A + / A –**) takes place in two Phases. Phase **A –** is the start position.
Pos. 2: the cycle of the cylinder **B** (**B + / B –**) takes place in three Phases. In this case Phase **B –** is not the start position.

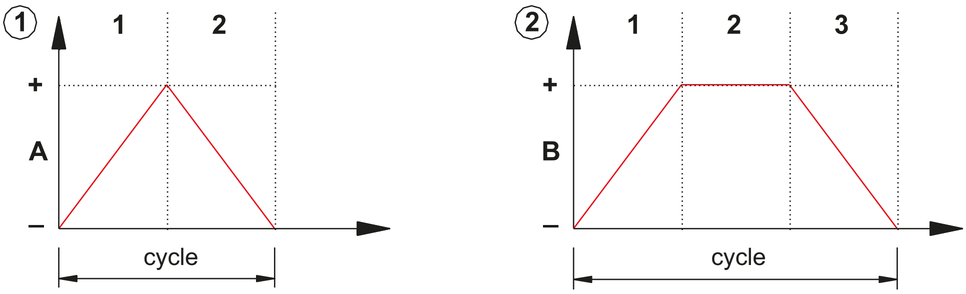


Fig. 23

When more than one cylinder is present in the same circuit, the following literal representation applies:

A + B + / A – B –
1 2

The cycle operates in two Phases:
- in the first we have the **A +** and **B +** movements simultaneously,
- in the second **A –** and **B –** simultaneously.

A + / B + / A – B –
1 2 3

The cycle operates in three Phases:
- in the first **A +**,
- in the second **B +**,
- in the third **A –** and **B –** simultaneously.

Graphical representation of multiple cylinders, we examine the following cycle as an example.

A + / B + / A – B –
1 2 3

Figure 24
Pos. 1: preparation of the flow diagram, insert the same amount of rows as cylinders.
Pos. 2: the first step involves inserting the names of the cylinders in the rows and illustrating the position they assume at the beginning of the cycle.
Pos. 3: the movement of the cylinders is represented “step by step”. An oblique line is traced inside the relevant section, starting from the initial position, to the target position. Where the cylinder remains unchanged over the course of the stroke, the line indicating the phases in which there is no movement is extended horizontally. In this Phase cylinder **A** must reach positive end position **A +**, the cylinder **B** does not move, therefore the horizontal line is extended.
Pos. 4: in the second Phase the cylinder **B** must reach the positive end position **B +**, we proceed in a similar way as in the previous case, tracing an oblique line within the cell formed by the intersection of the line of cylinder **B** with Phase 2. In this same Phase, but with reference to cylinder **A**, the line is extended, as the cylinder remains stationary.
Pos. 5: in the third phase both cylinders must return to the negative end position, **A – B –**.
Pos. 6: the cycle is complete, and we resume with Phase one. The length of the cycle is indicated in the lower part of the flow diagram.

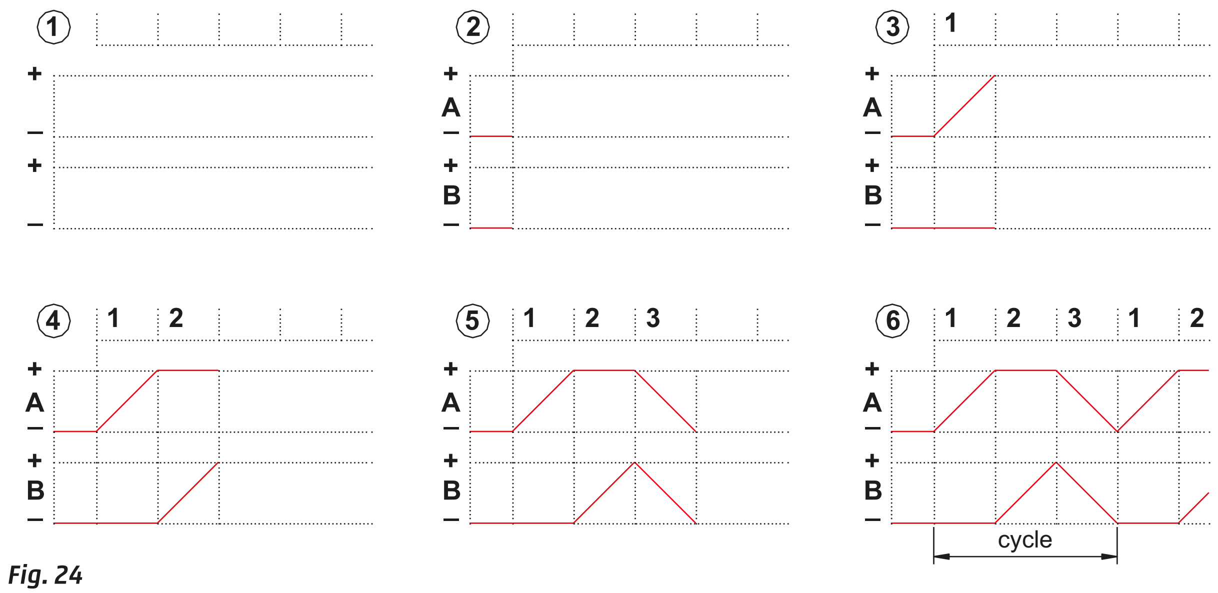


Fig. 24

Flow diagram with various examples:

Figure 25
Pos. 1: manually positioned metal sheets are to be bent and have a hole punched on the short end. Devices with cylinders that perform certain operations in successive phases are required:

Phase 1 cylinder **A** extends and clamps the sheet for the whole duration of the operation **A +**

Phase 2 cylinder **B**, if the component is blocked it can perform the bending operation **B +**

Phase 3 cylinder **B** clears the working area to allow the next movement **B –**

Phase 4 cylinder **C** performs the hole punching **C +**

Phase 5 cylinder **C** clears the working area **C –**

Phase 6 cylinder **A** releases the sheet which can now be removed **A –**

In this case, no two movements are simultaneous, they are all sequential.

Representation of the sequence in literal form:

A +	/	B +	/	B –	/	C +	/	C –	/	A –
1		2		3		4		5		6

Pos. 2: graphical representation.

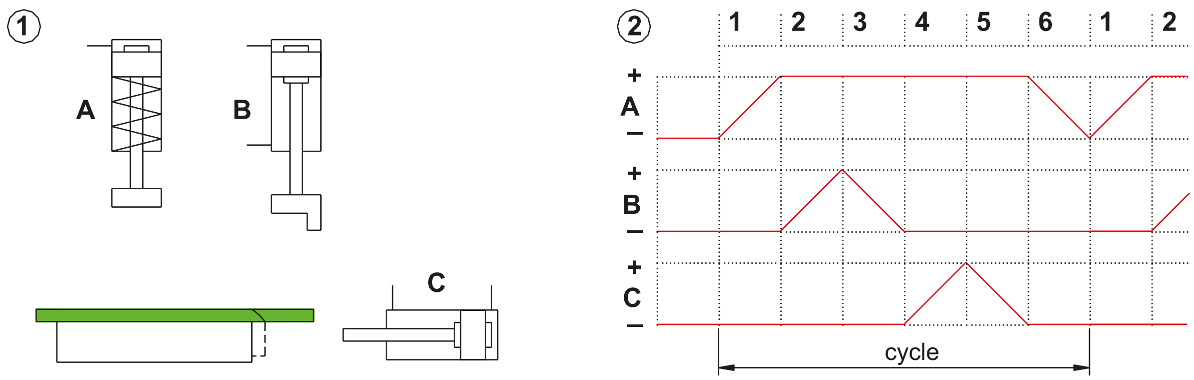


Fig. 25

Figure 26
Pos. 1: to a manually positioned component, a hole must be punched and discharged into a container. Also in this case we observe the cylinders performing the operations in successive phases:

Phase 1 cylinder **A** positions the component under the hole puncher **A +**

Phase 2 cylinder **A** clears the working area **A –**

cylinder **B** clears the working area **B +**

Phase 3 cylinder **B** returns directly after the punching operation **B –**

Phase 4 cylinder **C** retracts to discharge the component **C –**

Phase 5 cylinder **C** returns to position **C +**

In this case, during Phase 2, we observe the movement of the piston rod/piston of both cylinders **A** and **B**.

This sequence can be expressed in the following literal form:

A + / A – B + / B – / C – / C +
1 2 3 4 5

Pos. 2: graphical representation.

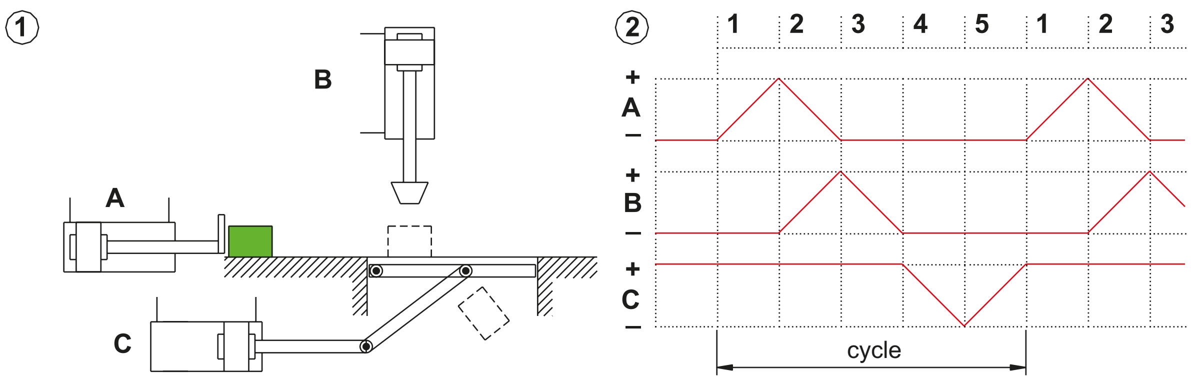


Fig. 26

Signals generated by limit switches

Limit valves (or limit switches) are normally mechanically operated and are used to detect the movement of the piston rod/piston in the cylinder or mechanical parts connected to them. The generated signal remains active throughout the period of operation and confirms the attainment of a certain position. Each limit switch is normally indicated by the lower case letter corresponding to the cylinder. The position is defined by a ZERO or ONE.

Cylinder **A** at negative end position, piston rod retracted **a0**

Cylinder **A** at positive end position, piston rod extended **a1**

Normally the output signals from the limit switches are used to permit the subsequent movements. On the flow diagram it is important to indicate the position of each limit switch and the destination of the output signals generated by them.

Figure 27
Cycle start: the piston rod/piston of the cylinders are at the negative end position, their respective main valves P_A and P_B are positioned so that the outgoing compressed air feeds the negative chamber. This position is determined by the last pilot signal received.

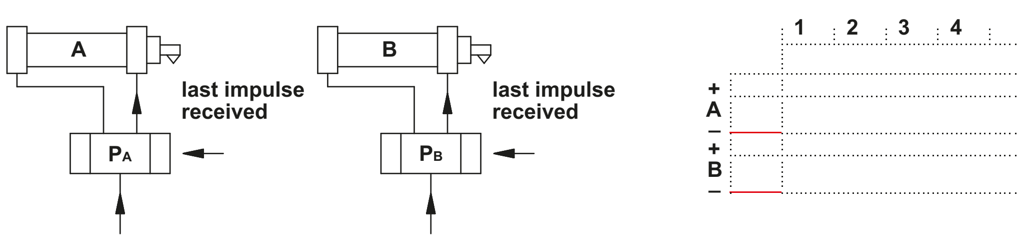


Fig. 27

Figure 28
Phase 1: by using a pilot valve with a push button, the actuating device on the left side of the valve **P**$_A$ is operated, which switches and feeds the rear chamber of cylinder **A**. Its piston rod/piston moves and advances to the positive end position actuating the limit switch **a1**.
Note: Observe that in the flow diagram, the output signal from the limit switch **a1** enables the movement of the piston rod/piston of the cylinder **B**.

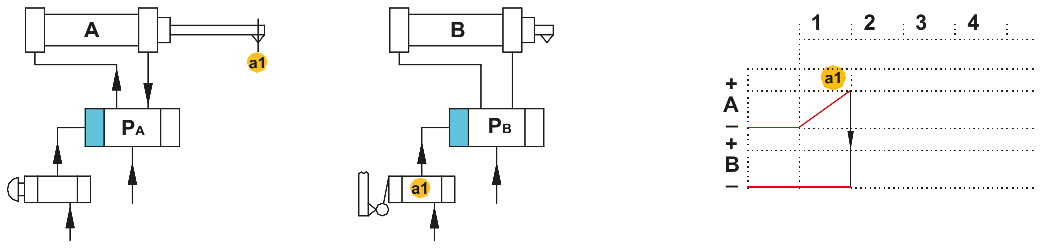


Fig. 28

Figure 29
Phase 2: the piston rod/piston of cylinder **A** remains stationary, the signal generated by the limit switch **a1** operates the actuating device on the left side of the valve **P**$_B$ which, by changing over, feeds the rear chamber of cylinder **B**. Its piston rod/piston reaches the positive end position, activating the limit switch **b1**.
Note: observe in the flow diagram, the output signal from the limit switch **b1** enables the movement of the piston rod/piston of cylinder **A**. During the stroke of cylinder **B**, the limit switch **a1** remains activated as the piston rod/piston of the cylinder **A** is stationary in the positive end position.

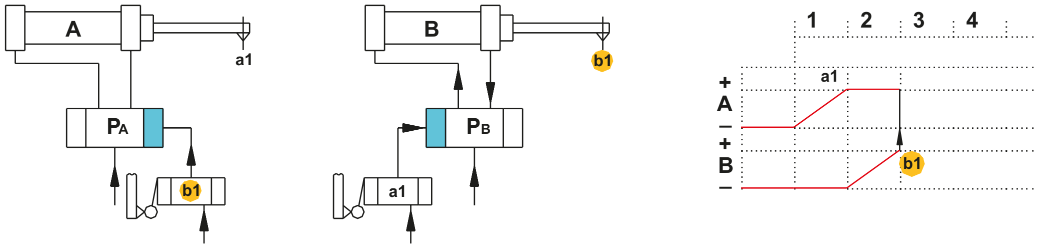


Fig. 29

Figure 30
Phase 3: the signal generated by the limit switch **b1** operates the actuating device on the right side of the valve **P**$_A$, which, through its changeover, feeds the front chamber of cylinder **A**. Its piston rod/piston moves, releasing limit switch **a1** and reaching the end position, thus activating the negative limit switch **a0**.
Note: observe that in the flow diagram, the output signal from the limit switch **a0** enables the movement of the piston rod/piston of cylinder **B**. During the stroke of cylinder **A**, the limit switch **b1** remains activated, as the piston rod/piston of cylinder **B** is stationary at the positive end position.

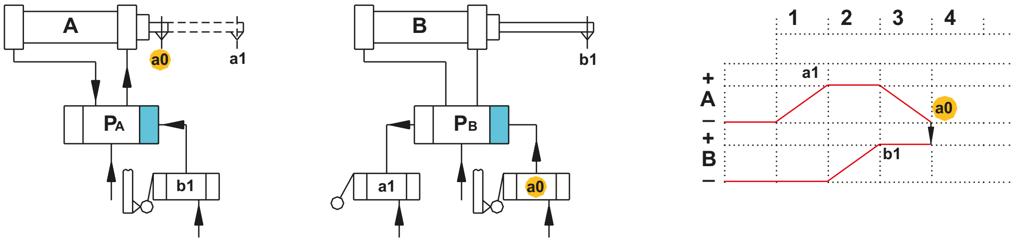


Fig. 30

Phase 4 in the previous paragraph this was not taken into consideration as it could create two different working modes: **single** cycle or **continuous**.

Figure 31
Phase 4: **Single Cycle**
The signal generated by the limit switch **a0** changes the position of the valve $\mathbf{P_B}$, the piston rod/piston of cylinder **B** returns to its initial position, the cycle stops where there is no limit switch. In Phase 1, the start signal to the valve $\mathbf{P_A}$ is provided by a manually operated monostable 3/2-way NC valve powered directly by the network.

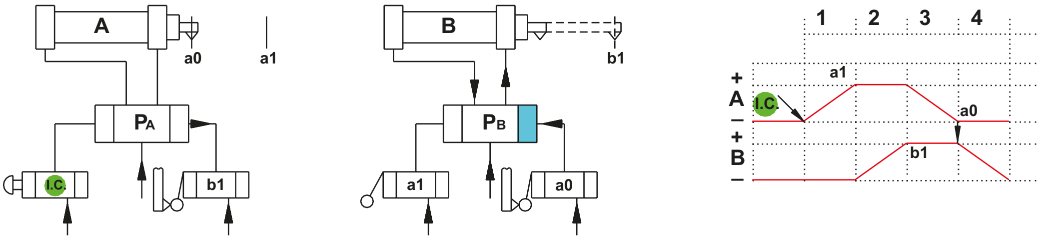


Fig. 31

Figure 32
Phase 4: **Continuous Cycle**
The signal generated by the limit switch **a0** changes the position of valve $\mathbf{P_B}$, the piston rod/piston of cylinder **B** returns to its initial position and actuates the limit switch **b0** (absente before).
Note: Note that in the flow diagram, the output signal from the limit switch **b0** enables the restart of the piston rod/ piston of cylinder **A**.

The limit switch **b0** is fed by the manually operated bistable 3/2-way NC valve **I.C.** If the valve **I.C.** is in the open position and with the actuation of the limit switch **b0**, the compressed air reaches the pilot signal of the main valve $\mathbf{P_A}$ for the repetition of the cycle.

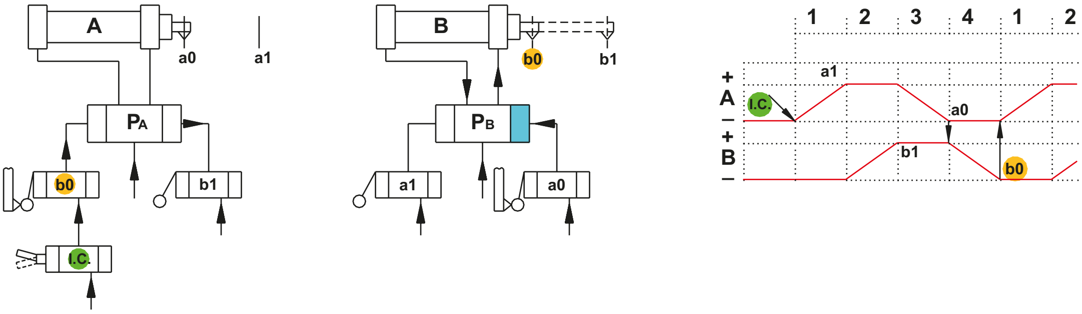


Fig. 32

As observed in Phases 2, 3 and 4, the continuing duration of the actuation on the limit switches and consequent presence of the output signals **does not obstruct the cycle**. It is important to take note of the relationship between **movements** and **signals**, essential for the resolution of the circuits.

Figure 33
We examine the continuous cycle as an example:
to obtain the stroke **A +** the output signals from **I.C.** and **b0** are necessary
to obtain the stroke **B +** the output signal from **a1** is necessary
to obtain the stroke **A –** the output signal from **b1** is necessary
to obtain the stroke **B –** the output signal from **a0** is necessary.

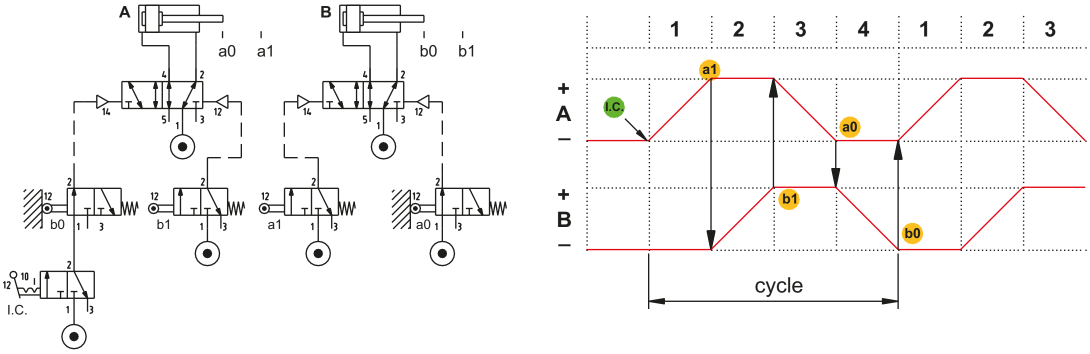


Fig. 33

We modify the previous sequence from:

A +	/	B +	/	A −	/	B −	to	A +	/	B +	/	B −	/	A −
1		2		3		4		1		2		3		4

which is operating with a continuous loop.
A new analysis of the circuit from the beginning of Phase 2 is required due to the change in movements of the last two phases of the circuit.

Figure 34
Phase 2: the signal generated by the limit switch **a1** changes the position of valve **P_B**, the piston rod/piston of cylinder **B** reaches the positive end position and actuates the limit switch **b1**, the limit switch **b1** generates a signal which allows the immediate return of the piston rod/piston of cylinder **B**. The signal **b1** cannot change the position of valve **P_B** as the signal from the switch **a1** is still present, being actuated by the piston rod of cylinder **A** still in this position. In order for the sequence to continue we need to remove the output signal from the limit switch **a1**.

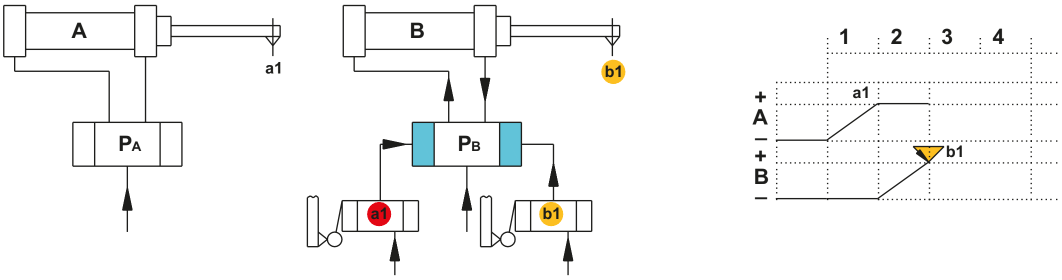


Fig. 34

Figure 35
Phase 3: we assume that we have removed **a1** (method will be shown later) and proceed with the cycle. The valve **P_B** changes position, the piston rod/piston of cylinder **B** returns and activates the limit switch **b0**.

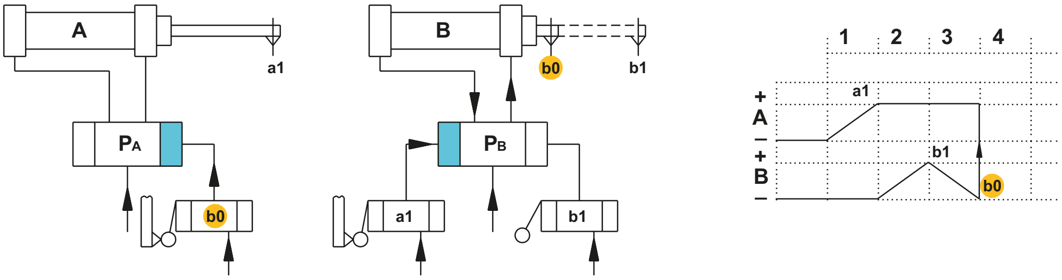


Fig. 35

Figure 36
Phase 4: the signal generated by the limit switch **b0** changes the position of valve **P_A** and the piston rod/piston of cylinder **A** returns to the start position. Once the cylinder **A** has returned to the start position, the limit switch **a0** is actuated again.

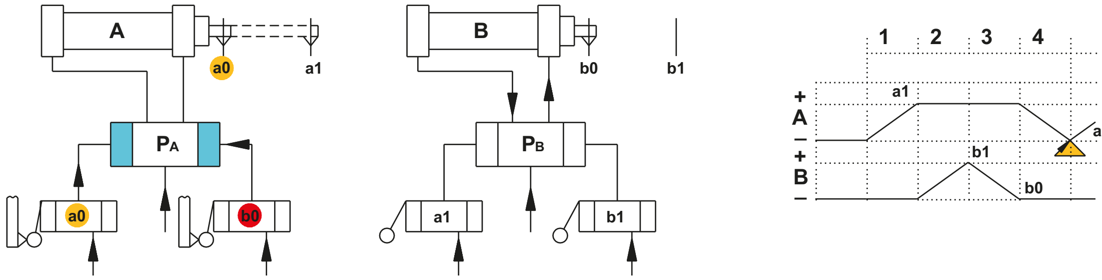


Fig. 36

The cycle should be repeated but cannot continue due to the presence of the pilot signal **b0** on the valve **P_A** preventing it from changing over, similar to Phase 2 where the signal is generated by the switch **a1**, these types of signals are called "**blocking signal**". The signal generated by the switch **b1** and **a0** is **instantaneous**.

Figure 37
Existing relationship between **movements** and **signals**:
to obtain the stroke **A +** the output signals from **I.C.** and **a0** are required
to obtain the stroke **B +** the output signal from **a1** is required
to obtain the stroke **B –** the output signal from **b1** is required
to obtain the stroke **A –** the output signal from **b0** is required.

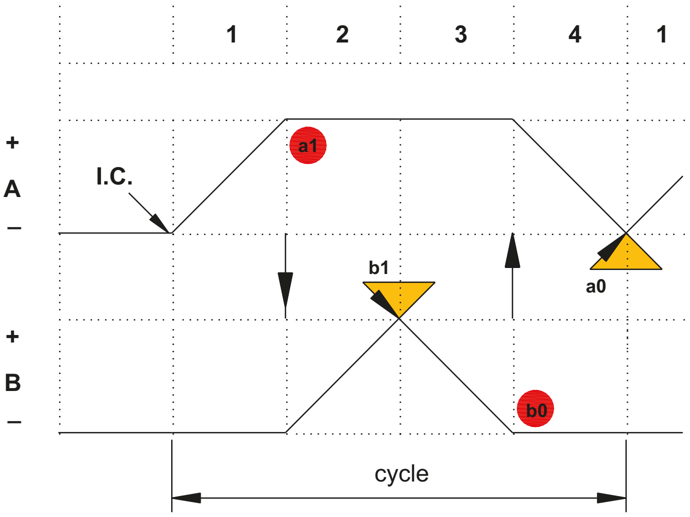


Fig. 37

Principles of logic

In any pneumatic automation, in addition to defining the sequence, it is necessary to implement all of the information required for its execution. To demonstrate we examine an automated sequence designed to separate bars for a subsequent selection. Schematic representation of the sequence:

Figure 38
Pos. 1: information "**a**" indicates whether the separator has loaded the bar.
Pos. 2: information "**b**" verifies that there are bars present in the stock.
Pos. 3: information "**c**" indicates that the discharge zone is free.
Pos. 4: mathematical logic is based on the two states **TRUE** or **FALSE**, with a numerical value assigned to each respectively:

TRUE = **1** **FALSE** = **0**

We apply this logic to our example

Information "**a**"	Has the separator loaded a bar?	TRUE	**a** = **1**
Information "**b**"	Are there bars present in the stock?	TRUE	**b** = **1**
Information "**c**"	Is the discharge zone free?	TRUE	**c** = **1**

This information combined together and processed, should result in command **X** as an output. In this case, as all pieces of information must be TRUE the mathematical rule and its result are:

$X = a * b * c$ $X = 1$

In this condition it is possible to have command **X** that enables the movement of the automatic sequence.

Pos. 5: One bar descends the rail.

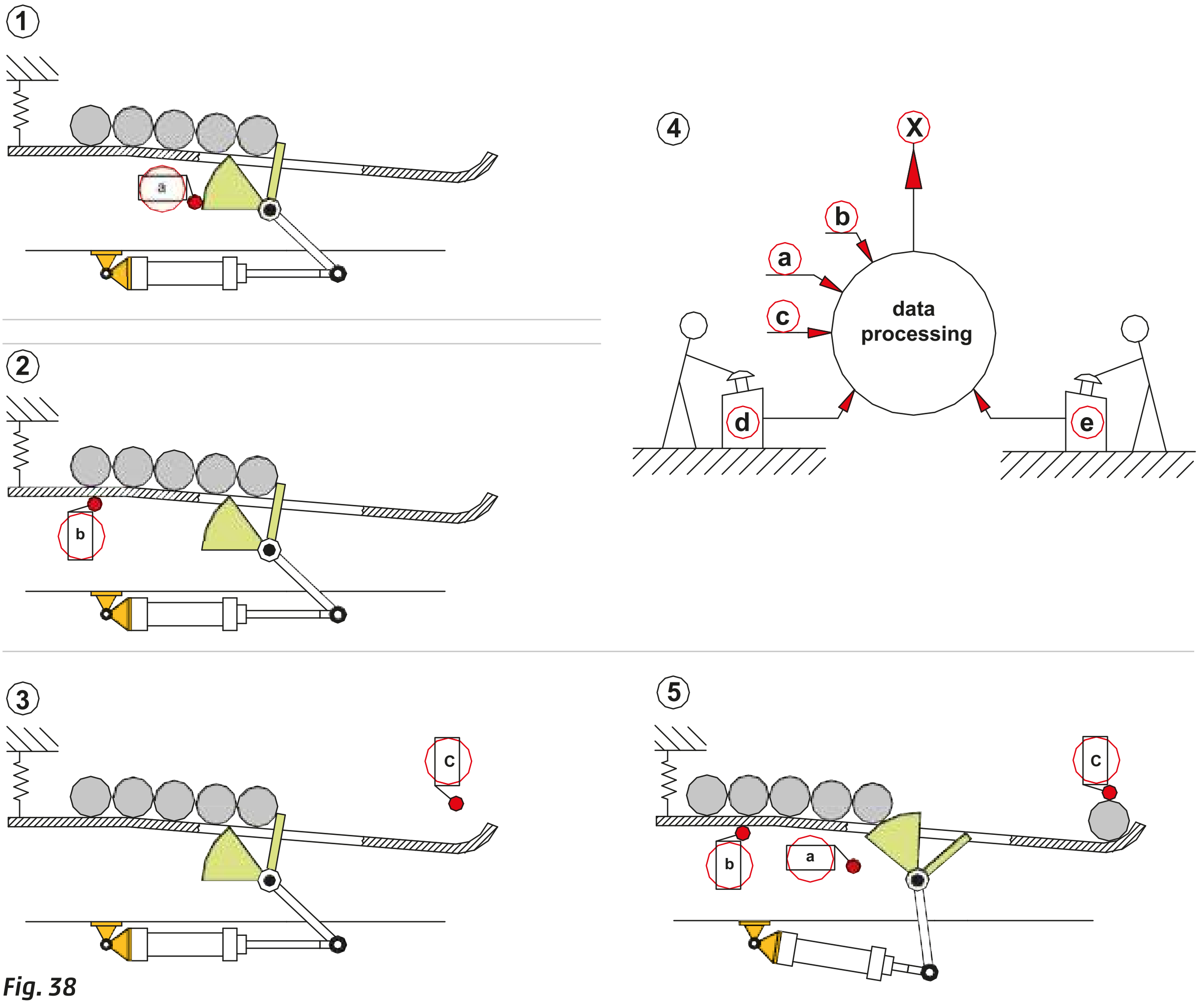


Fig. 38

Example 1
Marco will read (**X**) if he has a newspaper (**a**) and glasses (**b**).

The mathematical rule is:

$$X = a \ast b$$

Marco has a newspaper	**a** = **1**	he has his glasses	**b** = **1**	Marco reads	**X** = **1**
Marco has a newspaper	**a** = **1**	does not have his glasses	**b** = **0**	Marco does not read	**X** = **0**
Marco does not have a newspaper	**a** = **0**	he has glasses	**b** = **1**	Marco does not read	**X** = **0**
Marco does not have a newspaper	**a** = **0**	he does not have glasses	**b** = **0**	Marco does not read	**X** = **0**

Example 2
Luca reads (**X**) if he has a newspaper (**a**) or a book (**b**).

In this case, the required condition is that at least one of the two facts is TRUE, and the mathematical rule is:

$$X = a + b$$

Luca has a newspaper	**a** = **1**	has a book	**b** = **1**	Luca reads	**X** = **1**
Luca has a newspaper	**a** = **1**	does not have a book	**b** = **0**	Luca reads	**X** = **1**
Luca does not have a newspaper	**a** = **0**	has a book	**b** = **1**	Luca reads	**X** = **1**
Luca does not have a newspaper	**a** = **0**	does not have a book	**b** = **0**	Luca does not read	**X** = **0**

In pneumatics a valve can be: Open (**1**) or Closed (**0**), this state correlates with the mathematical logic, a subject we will address later on.

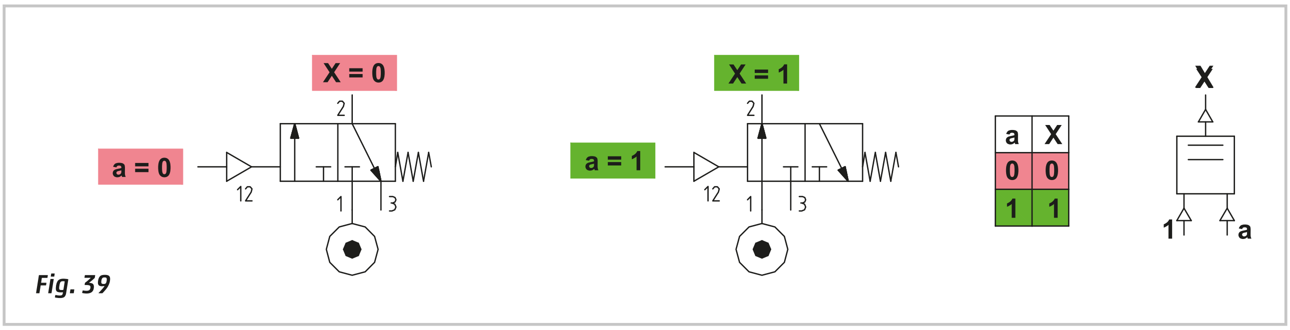
The basic logic functions

The rules of logic that imply a **0** or **1** status adapts well to pneumatically operated valves.
The principle logic functions pneumatically obtainable are: **YES**; **NOT**; **AND**; **OR**.

Figure 39
YES function
The valve which achieves this function is a **monostable 3/2-way NC** valve. Let "**a**" indicate the **0** or **1** status of the pilot signal, let **X** indicate the **0** or **1** status of the outlet signal from outlet 2;

If **a** = **0** then **X** = **0**; if **a** = **1** then **X** = **1**

$$X = a$$



a	X
0	0
1	1

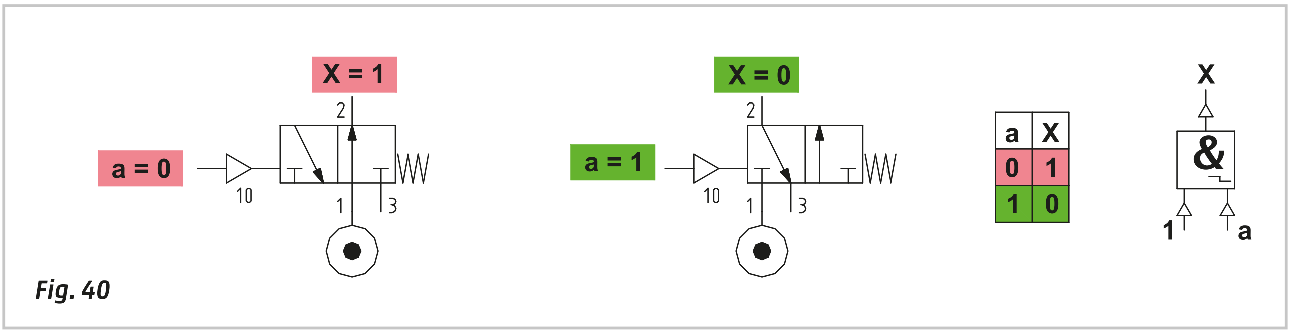
Fig. 39

Figure 40
NOT function
The valve which achieves this function is a **monostable 3/2-way NO** valve. Let "**a**" indicate the **0** or **1** status of the pilot signal, let **X** indicate the **0** or **1** status of the output signal at outlet 2;

If **a** = **0** then **X** = **1**; if **a** = **1** then **X** = **0**

a = **0**, when the information "**a**" is not present (FALSE), then **X** = **1** (it is present, TRUE)

$$\bar{a} = X$$



a	X
0	1
1	0

Fig. 40

Figura 41
AND function
This valve will only give an output signal if the two pilot signals are present.
There is an output signal **X** only if **a** = **1** and **b** = **1**.
The presence of two pilot signals, whereby each may have two states, brings the total of possible combinations to four, but only in one of them does the variable **X** have status **1**.

If **a** = **0** and **b** = **0** then **X** = **0**; there are no signals present

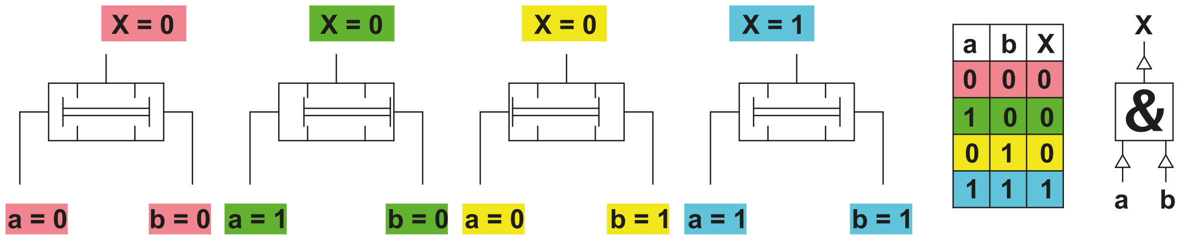
If **a** = **1** and **b** = **0** then **X** = **0**; the input signal moves the internal piston
to the right preventing passage towards **X**

If **a** = **0** and **b** = **1** then **X** = **0**; the input signal moves the piston
to the left preventing the passage towards **X**

If **a** = **1** and **b** = **1** then **X** = **1**; if the pressures are equal, the most recent signal passes,
if the pressures are different the signal with the lower pressure passes.

The product of the status of the two variables "**a**" and "**b**" determines the status of output **X**.

$$X = a * b$$



a	b	X
0	0	0
1	0	0
0	1	0
1	1	1

Fig. 41

Figure 42
OR function
This valve gives an output signal if at least one of the two pilot signals is present.
There is an output signal **X** only if "**a**" or "**b**" are **TRUE** (they are present).
The presence of two pilot signals, whereby each may have two states, brings the total possible combinations to four, in three of these combinations the variable **X** has status **1**.

If **a** = **0** and **b** = **0** then **X** = **0**; there are no signals present

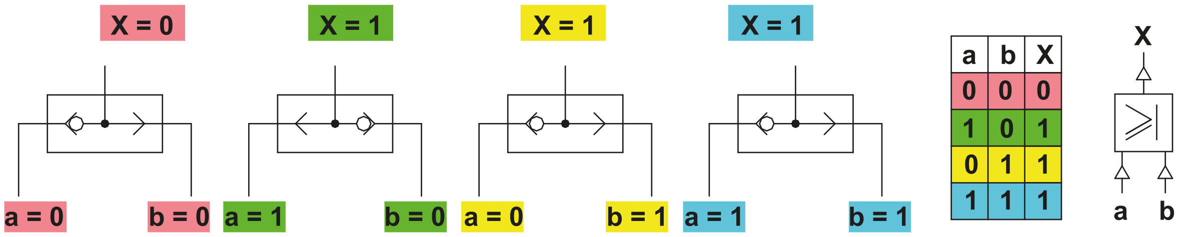
If **a** = **1** and **b** = **0** then **X** = **1**; the input signal from "**a**" pushes the sphere towards "**b**" closing the passage towards **X**

If **a** = **0** and **b** = **1** then **X** = **1**; the input signal from "**b**" pushes the sphere towards "**a**" closing the passage towards **X**

If **a** = **1** and **b** = **1** then **X** = **1**; if the pressures are equal, the first received signal passes, if the pressures are different the signal with the higher pressure passes through.

The sum of the two variables "**a**" and "**b**" determine the status of **X**.

$$X = a + b$$



a	b	X
0	0	0
1	0	1
0	1	1
1	1	1

Fig. 42

An example of the application of basic logic functions

We use the previously analysed bar handling plant as our example, describing its operation according to the principles of logic.

The initial conditions required are:
IF the separator has loaded the bar, information "**a**"
AND there are other bars in the stock, information "**b**"
AND there are **NOT** bars located on the discharge zone, information "**c**"
THEN it is possible to control the cylinder from a certain position, information "**d**"
or from another position, information "**e**"

The condition can also be written in the following way:
"**a**" **AND**, "**b**" **AND**, "**c**" **AND** "**d**" or "**e**" then the logic equation **X** is as follows:

$$X = a \ast b \ast c \ast (d + e)$$

The parenthesis encompassing the information"**d**", "**e**" in the equation, signify that in the presence of the **AND** of "**a**" $\ast$ "**b**" $\ast$ "**c**", only **d**) or **e**) are necessary to start the cycle. Once the problem has been translated into a logical form, we analyze the procedure for the preparation of the pneumatic circuit:

Figure 43
Type of limit valves (switches):

information "**a**"	the separator has uploaded a bar. This limit switch is activated by the position of the separator. Here we use a **3/2-way NC** valve which, when **activated**, has outlet with status **1**
information "**b**"	at least one bar is present in the stock. This limit switch is activated by the presence of the bar. Here we use a **3/2-way NC** valve which, when **activated**, has outlet with status **1**
information "**c**"	there are no bars on the discharge area. This limit switch need not be activated and must be confirmed to not be so. Here we use a **3/2-way NO** valve which, when **not activated**, has outlet with status **1**

information "**d**", "**e**" here we use manually operated **3/2-way NC** valves which, when **not activated** have the outlets with status **0**

Information path of the limit switches:
The initial condition required in order to activate the device is given by the equation:

$$a \ast b \ast c$$

One solution is to connect the three valves in "series", i.e. to feed only the first with compressed air; the outlet of this will feed the second whose outlet will feed the third. The same function can be obtained with the **AND** element which has only two pilot ports, while in this case three signals are required, therefore two **AND** elements are needed.

The path of the two control signals:
The signals "**d**"; "**e**"can be generated by two separate 3/2-way NC valves, both separated from each another, but equally capable of enabling the start of the cycle. The destination of these two signals is the same so they must be united into a single logical element, permitting at least one of the two input signals to continue. The suitable logic element for this function is the **OR** element.

Unification of the two signal groups: with (**d + e**):
The output signal **X** from the logical equation (**a** $\ast$ **b** $\ast$ **c**) must be in **AND** with the output signal **X** in the logical equation (**d + e**), the final output **X** controls the main valve which in turn activates the outward movement of the cylinder.

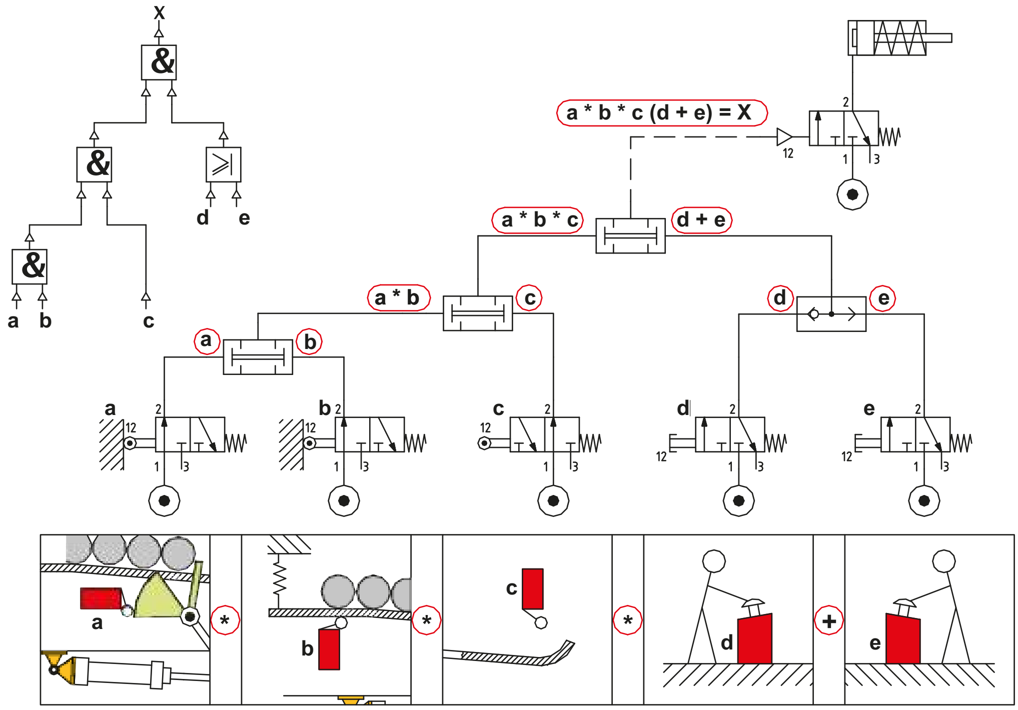


Fig. 43

Use of logic functions YES and NOT

Figure 44
YES function
Pos. 1: we have a pneumatically operated monostable **3/2-way NC** valve requiring low pilot pressure. It can be used to amplify the pilot signal.
Pos. 2: the **YES** component, connected to the two valves functions as **AND**. By activating the valves manually, mechanically or otherwise, signals "**a**" and "**b**" are generated and connected to the inlet 1 and pilot port 12 of **YES**. With the presence of both signals the output is obtained.
Pos. 3: with the main valve in this position, the rear chamber of the cylinder is exhausted and there is no pilot signal on the **YES**, its outlet "**a**" is not pressurized. Also the manual valve which is in rest position has no outlet.

In this condition the logic equation is: if **a** = **0** then **X** = **0**

With the activation of the manual valve, the main valve changes over causing the cylinder to complete the positive stroke and transmitting the pilot signal to the **YES** valve. Its outlet 2, feeding only pilot port 12 of the main valve, does not change status as long as the manual valve remains activated. When the manual valve is released, the cylinder will reverse its stroke, regardless of the position of the cylinder at that moment.

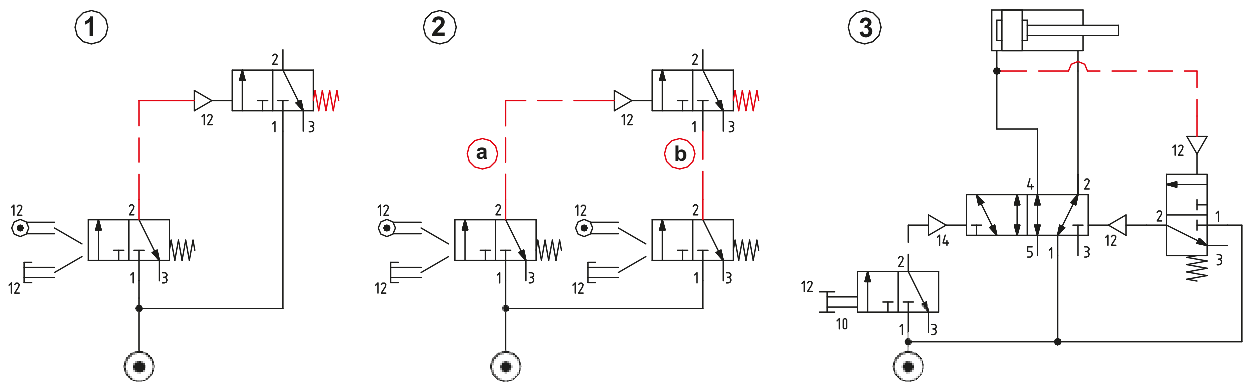


Fig. 44

Figure 45
NOT Function
Pos. 1: we have a small-dimensioned pneumatically operated monostable **3/2-way NO** valve. The low pressure pilot required for activation may be used to control the pressure inside the chamber.

The logic equation is: if **a** = **0** then **X** = **1**

Pos. 2: inversion of the signal coming from an **AND** element
The **AND** element generates an output in the presence of its two pilot signals, it is possible to create a **NAND** function (Negated **AND**) by connecting the output of the **AND** to the **NOT**.
Presuming the output of the function **AND** towards the **NOT** is active, then **X** = **0**.

Signal inversion coming from an **OR** component.
The **OR** element generates an output signal in the presence of at least one of its two pilot ports, it is possible to create a **NOR** function (Negated **OR**) by connecting the output of the **OR** to the pilot port of the **NOT**.
As long as the output of the function **OR** towards the **NOT** is active, **X** = **0**.

In both cases, the logic equation is: if **a** = **1** then **X** = **0**

Pos. 3: use of the **NOT** function as a limit switch.
By activating the manual valve, the main valve changes over and the supply of the cylinder chambers is reversed. The pilot port of the **NOT** function continues to be fed by the air pressure exhausted from the cylinder, and the NOT remains piloted until the pressure in the exhaust reaches the minimum value for the pilot signals (about 0.2 *bar*).

When the pressure reaches this value, we have: if **a** = **0** then **X** = **1**

The output **X** of the **NOT** function is connected to pilot port 12 of the 5/2-way valve, and it has a momentary effect, in fact immediately after the valve changeover, outlet 2 is again pressurized, restoring the condition: if **a** = **1** then **X** = **0**

The manual valve is now ready for a new operation.

Note: when using the **NOT** function as a limit switch, it is important to consider that output **X** is present in the event of an external mechanical stop of the piston rod/ piston before the end of the stroke. In addition, any adjustments to the velocity are to be made on the exhaust of the 5/2-way valve. With flow regulators placed on the cylinder ports, the pressure in the tube between the main valve and flow regulation valve is quickly reduced and may not be sufficient to maintain the **NOT** piloted, which would activate the output **X**.
In this case we would have a false reading, as the cylinder would still be moving and not at the end position.

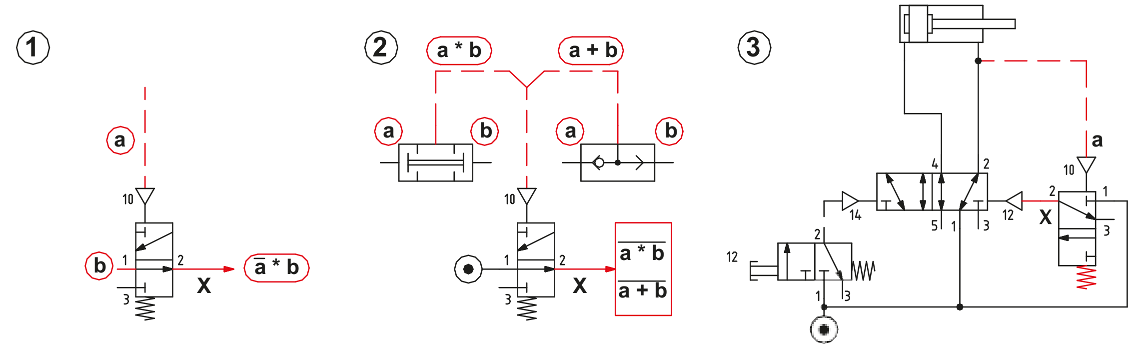


Fig. 45

OR and AND achieved with (3/2-way) directional control valves

Logic function AND

The **AND** function presupposes the presence of the information (i.e independent signals) "**a**" and "**b**" at its two inlets to generate the output signal **X**. Two 3/2-way valves connected in a suitable manner can also achieve the same logic function.

Figure 46
Two valves, the first with its inlet connected to the compressed air network, the 2nd fed from the outlet of the first. The two valves are connected in series, both are 3/2-way **NC** and only if operated simultaneously, do they generate their respective signals "**a**" and "**b**" with the consequent result **X**.

Logic equation with the AND function:	$a * b = X$
Logic equation with distribution valves:	$a * b = X$

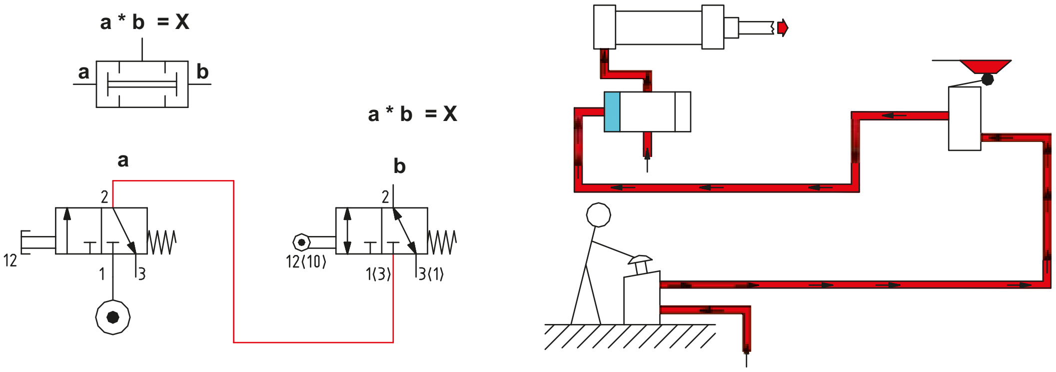


Fig. 46

Logic function OR

The **OR** function presupposes the presence of at least one of the two independent signals "**a**" or "**b**" at its two inlets to generate the output signal **X**. Two 3/2-way valves, connected in a suitable manner can achieve the same logic function.

Figure 47

The valve that generates signal “**a**” will have its inlet 1 connected to the compressed air network, the valve that generates signal “**b**” will have its inlet 1 connected to the compressed air network and its exhaust port connected to the outlet of the first valve through port 3. This valve must be a spool valve. In this way the signal **X** can be generated with the presence of only one signal from any of the two valves.

Logic equation with the OR function:	a + b = X
Logic equation with 3/2-way valves:	a + b = X

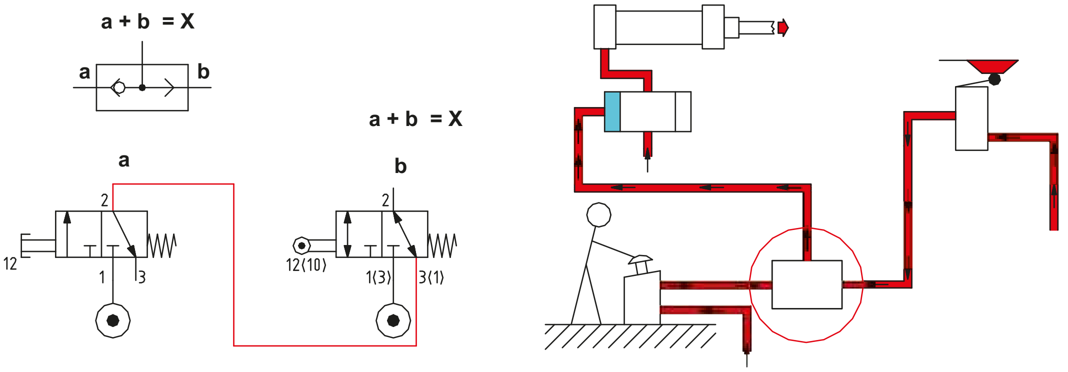


Fig. 47

Memory valves

The output signal generated by any monostable valve has the same duration as its pilot signal. These and other signals can be processed through the logic functions **AND** and **OR**. The output signals from these two components have the same duration as their input signals.

In many circuits, the short duration of one single signal may prevent the completion of the sequence, hence the necessity for a valve that can maintain the ONE state of a signal, i.e, to “memorize” the information.

The memory valve is in fact a normal pneumatically operated bistable **3/2-way** or **5/2-way** valve.

Figure 48

Operation of a 3/2-way memory valve

Pos. 1: **b** = **1**	**X** = **0**	
Pos. 2: **b** = **0**	**X** = **0**	the valve remains in the previous position
Pos. 3: **a** = **1**	**X** = **1**	signal “**a**” changes the valve over, putting inlet 1 in communication with outlet 2
Pos. 4: **a** = **0**	**X** = **1**	the valve remains in the previous position
Pos. 5: **b** = **1**	**X** = **0**	the valve has been positioned and maintains its position even in the absence of signal.

The memory valve receives the signal **a** = **1**, which results in **X** = **1**.
This output will be maintained with or without the presence of signal “**a**” as long as signal “**b**” is not given (signal “**a**” must be removed).

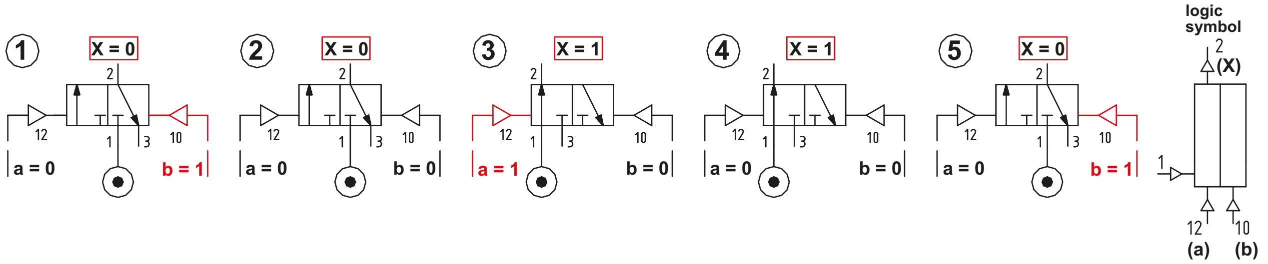


Fig. 48

Figure 49

Prolonging the effect of signal “a”

From the manual or mechanical valve, signal “**a**”
reaches pilot port 12 of the memory activating its output. **a** = **1** **X** = **1**

Upon interruption of signal “**a**”, the output remains active. **a** = **0** **X** = **1**

To remove the output **X**, signal “**b**” is required. **b** = **1** **X** = **0**

The duration of output **X** is the period between the arrival of signal “**a**” and signal “**b**”.
Even if signal “**a**” were to be a very short impulse the same rule would apply. It can be beneficial to represent the status of the signals and output over time on a diagram. The unit of time is not indicated.

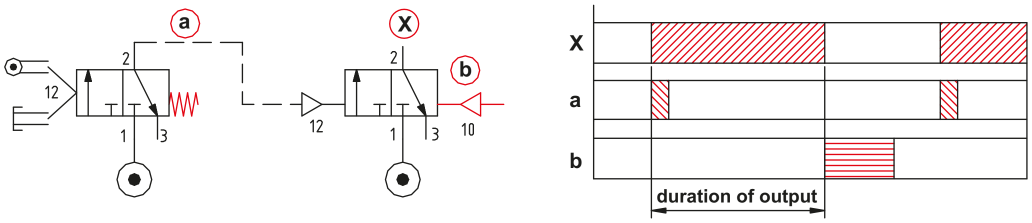


Fig. 49

Figure 50

Memory usage with blocking signals.

The memory valves in a circuit can be used to manage momentary signals in addition to continuous signals, specifically those defined as blocking signals. In order to remain within a certain time limit which is established by the necessity of the circuit, also in this case we use a bistable 3/2-way valve with memory function.

The starting condition is; **X** = **1** in the presence of signal **K**, i.e. the memory will have received the signal “**a**”.
The signal **K**, passing through the memory becomes **X**, its duration depends on the arrival of the signal “**b**”.
The signals “**a**” and “**b**” may be short momentary impulses, and may also be different from one another.

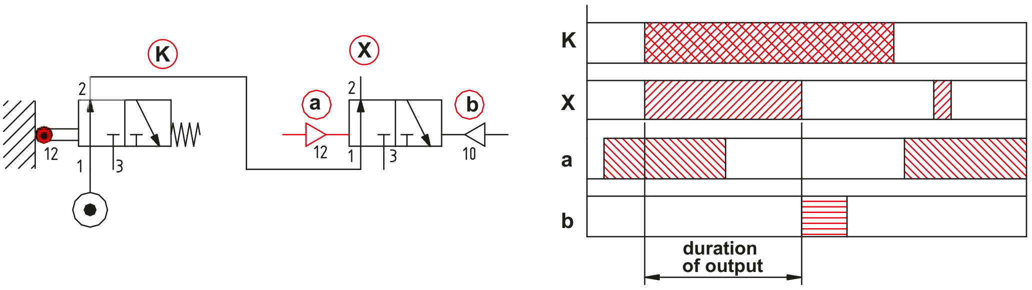


Fig. 50

The **5/2-way** memory valve differs from the 3/2-way in that it has two separate outlets, each of which may alternately assume state **ZERO** or **ONE**.
The signals “**a**” and “**b**” change over the memory outputs “**X**” and “**K**”respectively.

Figure 51

Pos. 1: if **a** = **0** and **b** = **1** then **K** = **1** and **X** = **0**
At the interruption of information “**b**” the memory maintains (has memorized) the position if **a** = **0** and **b** = **0** the **K** = **1** and **X** = **0**
Pos. 2: if **a** = **1** and **b** = **0** then **K** = **0** and **X** = **1**
At the interruption of information “**a**” the memory maintains the position if **a** = **0** and **b** = **0** then **K** = **0** and **X** = **1**

The continuous presence of one of the two signals “**a**” or “**b**” does not permit to change the state of the memory.

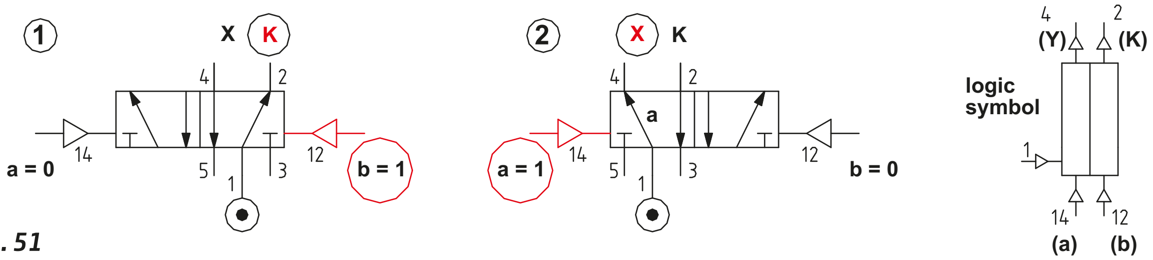


Fig. 51

Figure 52
Using the memory valve fed by the compressed air network.

Two limit switches 3/2-way NC monostable are fed alternately by the **X** and **K** of a memory. The outputs of the limit switches will only be present in the presence of the command on their respective actuation device.

Memory			Left limit switch		Right limit switch	
	Signal	Outlet	Actuation	Outlet	Actuation	Outlet
Pos. 1	a = 0	X = 0	Absent	0	Present	1
	b = 0	K = 1				
Pos. 2	a = 1	X = 1	Absent	0	Present	0
	b = 0	K = 0				
Pos. 3	a = 0	X = 1	Present	1	Absent	0
	b = 0	K = 0				

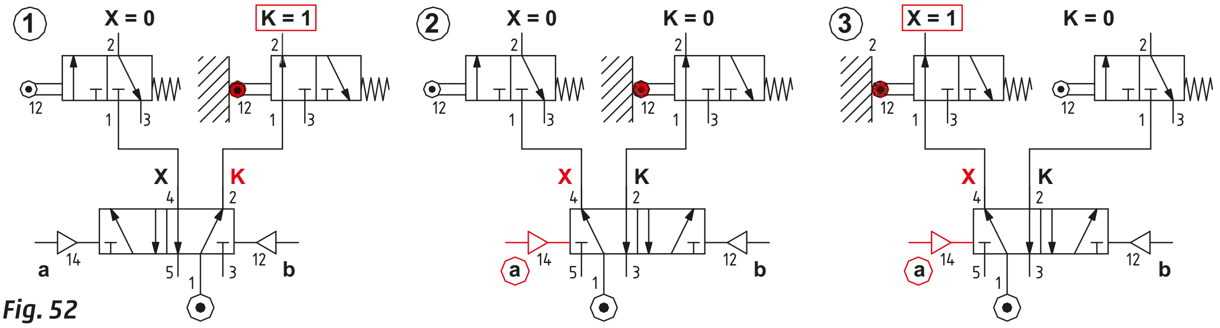


Fig. 52

Figure 53
Using the memory valve fed with compressed air by another valve.

The outputs **X** and **K** depend on the presence of compressed air and from the signal "**a**" and "**b**".
For ease of readability, the diagram has been divided into equal parts.

Time 0-1: signal "**b**", arrives; the memory is positioned in such a way that in the presence of compressed air, the outlet **K** is active.
S = 0 K = 0 X = 0

Time 1-2: signal "**b**" is interrupted, compressed air is present, the memory state does not change and the output **K** is activated.
S = **1** K = **1** X = 0

Time 2-3: even in the absence of signal "**a**" or "**b**" the memory state does not change and remains in the position defined by the last received signal (**b**).

Time 3-4: signal "**a**" arrives; the memory is positioned so that the compressed air is in communication with the outlet **X**.
S = **1** K = 0 X = **1**

Time 4-5: the compressed air is not present and there are no output signals. The presence of signal "**a**" does not alter the situation.
S = 0 K = 0 X = 0

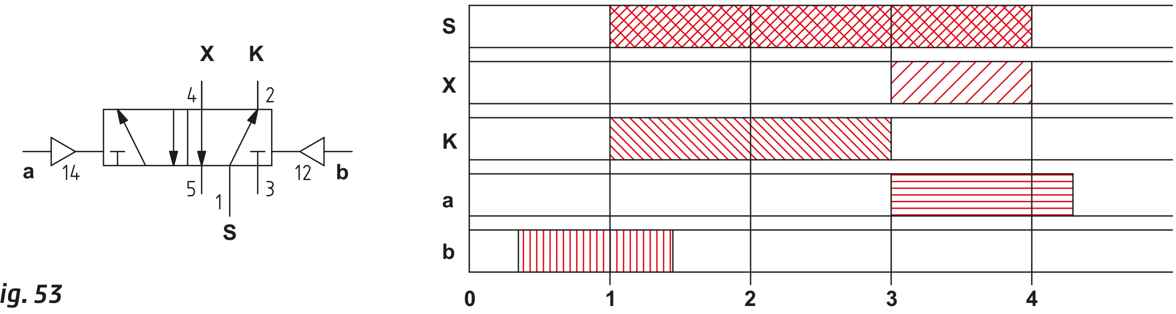


Fig. 53

The timer

The function of the timer is to regulate the duration of a signal.

Figure 54
Pos. 1: when the cylinder activates the limit switch, both the output "**a**" and the changeover of the main valve for subsequent movement are immediate. A timer is installed if the cylinder is required to remain at the end position for a given amount of time before returning. This timer sends an output "**x**" once the required time has passed.
Pos. 2: a timer may be "constructed" by connecting pneumatic components.
A unidirectional flow regulator regulates the amount of air inside a circuit, which comprises a reservoir and the pilot port of a 3/2 valve. The regulator can be connected in two modes; to regulate the "**input**" or the "**exhaust**"; this will delay the actuation of the 3/2-way valve or keep it actuated for a certain amount of time after the signal "**a**" has been discontinued.
The regulation of the flow control valve: the less air that is allowed to pass (smaller flow), the longer it takes for the reservoir to fill and actuate/release the valve.
A capacity/reservoir: the larger its volume, the greater the time "**t**" needed to fill or empty it through the reduced cross section created by the flow regulator, whereby the internal pressure reaches the value required to actuate/release the valve.
A 3/2-way valve: NC or NO depending on the type of function requested by the timer.

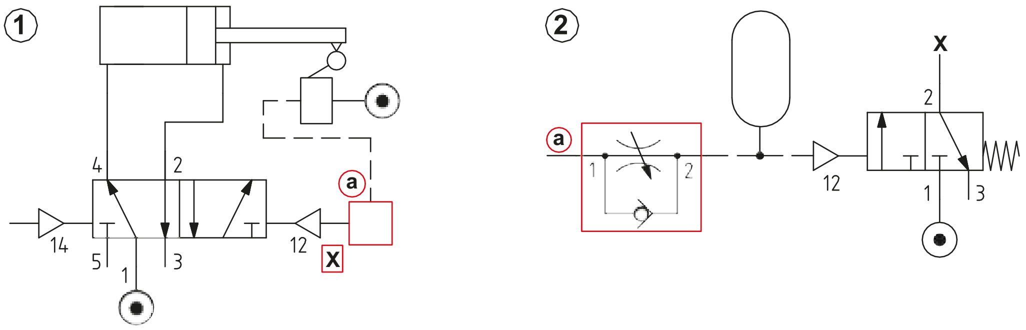


Fig. 54

Figure 55
Pos. 1: delaying of signal "**a**".
The reservoir is filled slowly as the flow regulator is reducing the flow. The valve is actuated with a delay "**t**" after the arrival of the signal "**a**" regardless of whether it may be a **3/2-way NC** or **3/2-way NO**.
Pos. 2: maintaining signal "**a**" after its interruption.
The reservoir is slowly exhausted as the flow regulator reduces the flow; signal "**a**" is maintained for a certain amount of time after its interruption. The valve returns with a delay "**t**" after the interruption of the signal "**a**", regardless of whether it is a **3/2-way NC** or **3/2-way NO**.
Pos. 3: a combination of the above.
There are two different delays, one during the filling phase and one during the exhaust phase of the reservoir. When signal "**a**" arrives, the reservoir fills slowly, as the flow regulator at the inlet is reducing the flow, delaying the actuation of the valve by time "t_1". When signal "**a**" is interrupted, the reservoir slowly empties as the exhausting flow regulator is reducing the flow; the valve remains actuated also in the absence of signal "**a**" for designated time, "t_2 ".

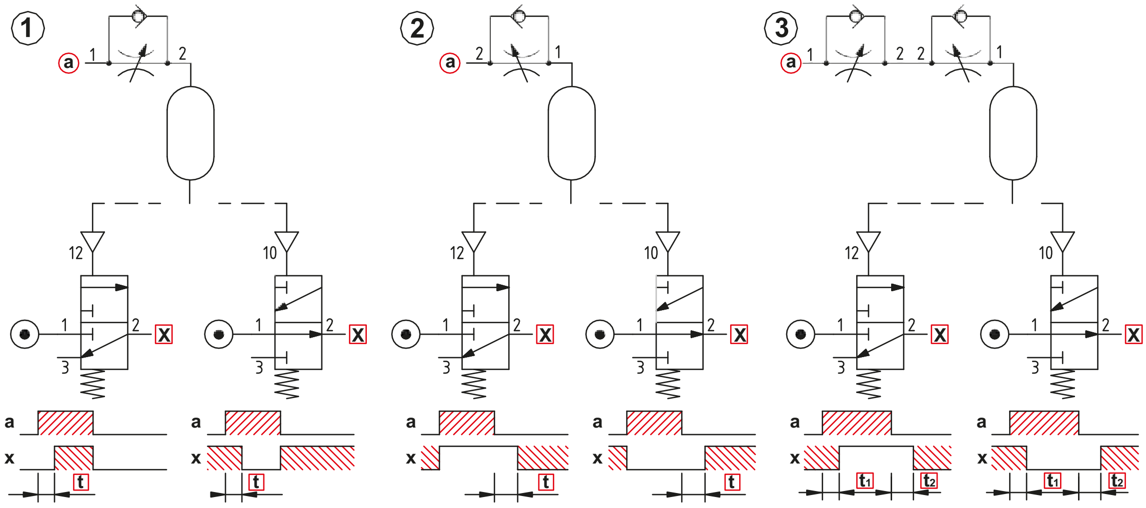


Fig. 55

Cycle start command

In a machine/plant, the sequence may be executed with both a **single** or semi-automatic cycle in addition to a **continuous** or **automatic** cycle. In both cases it is necessary for the start command to be given by a Start Cycle (**I.C.**) (Inizio Ciclo) valve. In a **single** cycle the command must be repeated each time the sequence restarts. In this case the valve that generates the start signal is a monostable valve. In a **continuous** cycle the command is only given at the start. In this case the valve that generates the start signal is a bistable valve.
In the continuous cycle the Start Cycle (**I.C.**) valve in the actuated position must be connected in series with the last signal to have confirmed the correct position of the actuators at the end of the sequence. When this valve is deactivated (i.e. no passage between inlet 1 and outlet 2), there is no continuous cycle and the start signal cannot restart the sequence.

Figure 56
Pos. 1: as the flow chart indicates, Phase 4 is the final phase, during this Phase **a0** is the last limit switch to be activated.
Pos. 2: the outlet of valve **a0**, i.e. the last signal to have confirmed the correct position of the actuators at the end of the sequence, feeds the **I.C.** valve, which in turn permits the passage of the signal although only if it is in **C.C.** (Continuous Cycle) position. In the position shown below the valve is closed indicating it is in the **F.C.** (End of Cycle) position. In the case of a monostable **I.C.** valve, the cycle would be a single cycle and would need to be operated at each sequence end.
Pos. 3: contrary to the previous situation, the **I.C.** valve is fed by the compressed air. It is only possible to generate the Start command when both the **I.C.** valve and the limit switch **a0** are operated.

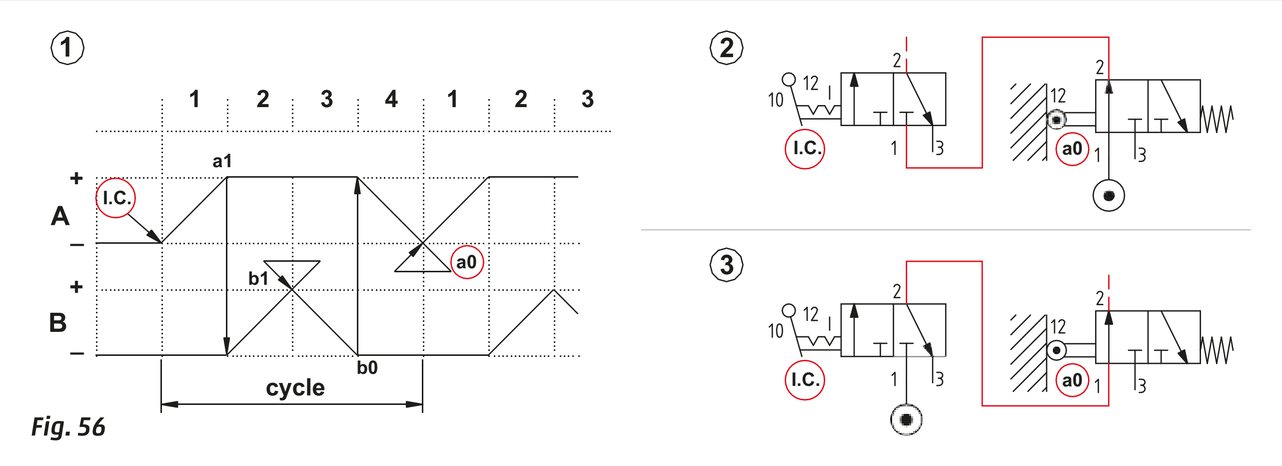


Fig. 56

Figure 57
Pos. 1: with the introduction of an AND valve, the two previous valves can be powered directly from the network. The **a0** valve is actuated and there is always a signal on the AND valve, the Start outlet is only active if the **I.C.** valve is actuated. The cycle is a single cycle.
Pos. 2: the same connection as the example in Pos. 1 with the introduction of two monostable 3/2-way NC valves, which allow the separation of the Start Cycle **I.C.** and End cycle **F.C.**, commands.
This condition requires the introduction of a double pneumatically operated bistable 3/2-way valve to memorize the signals from the two control valves.

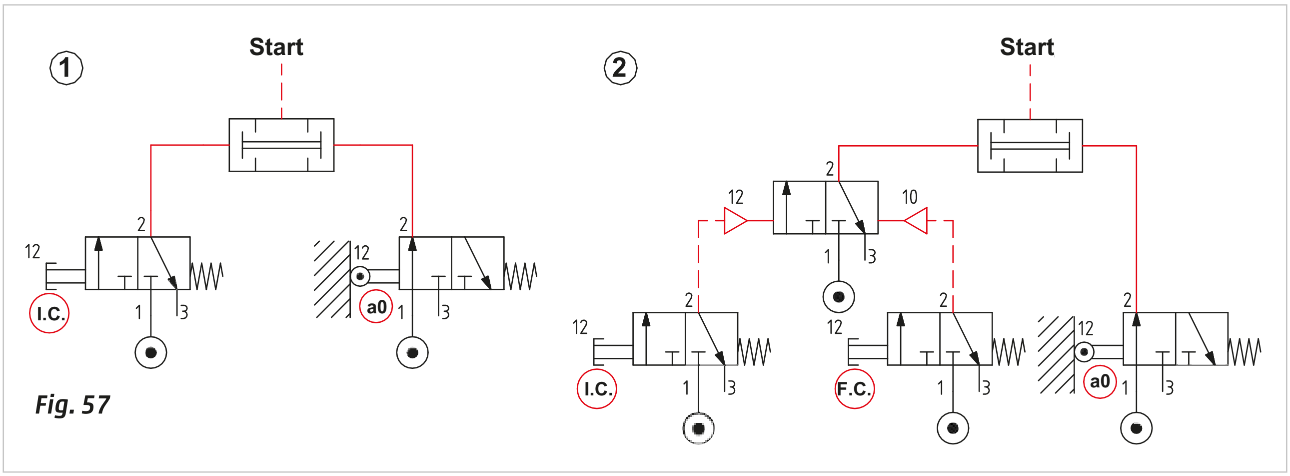


Fig. 57

The Start function can be achieved with manual monostable valves and manual bistable valves. The choice remains with the designer of the circuit to adopt the most adequate solution for the application involved.

Single/continuous cycle

As previously analyzed, a cycle can be single or continuous; this functionality can be implemented with multiple circuit solutions.

Figure 58
Single cycle: the compressed air feeds the **C.S.** (ciclo singolo)(single cycle) button, when activated, the signal "**a**" is forwarded to the **OR** and continues to the **AND**. In the presence of signal "**b**" generated by the switch **b0**, output **X**, which becomes the start signal, is obtained. The cycle requires the activation of the **C.S.** button to restart.
Automatic cycle: by pressing the **I.C.** button, an output signal is generated which operates the memory valve, this changes over and sends signal "**b**" to the **OR** and continues to the **AND**. In the presence of signal "**b**" generated by the limit switch **b0**, output **X** which becomes the start signal, is obtained.
The cycle continues to repeat itself as long as the End Cycle (**F.C.**) command remains non-actuated, as it repositions the memory valve to the closed position.

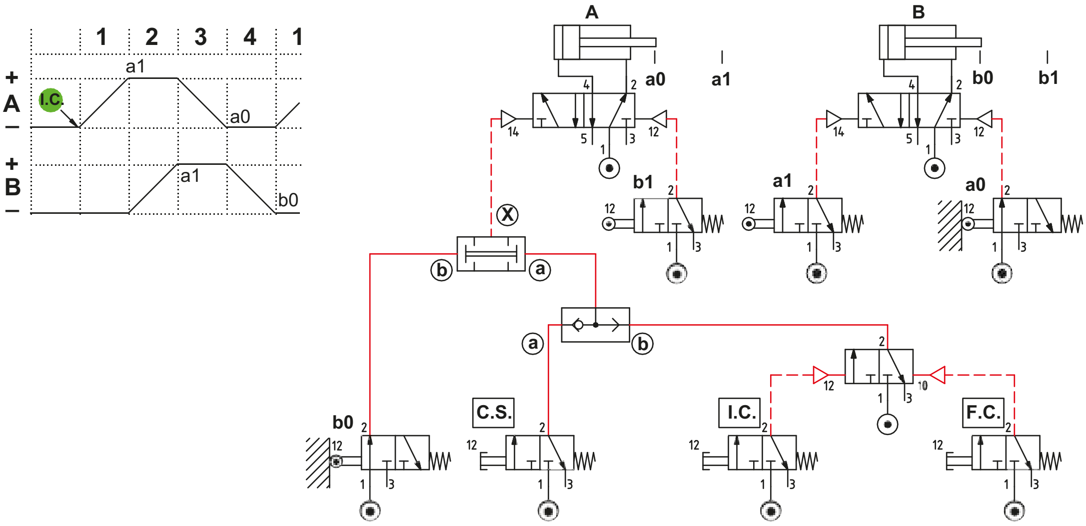


Fig. 58

Figure 59
The cycle is the same, with the exception of the beginning of the cycle- in particular the start signal. A bistable manual 5/2-way valve representing the functions **C.S.** (Single cycle) and **C.A.** (Automatic Cycle), have replaced the **I.C.**, **F.C.** and memory valves.
5/2-way valve in the Single Cycle C.S. position
The **C.S.** button is fed with compressed air by the 5/2 way valve, though in the closed position, signal "**a**", if operated, is forwarded to the **OR** and continues to the **AND**. In the presence of signal "**b**" generated by the switch **b0**, output **X** which becomes the start signal is obtained. The cycle requires the activation of the **C.S.** button to restart.
5/2-way valve in the Automatic Cycle C.A. position
Compressed air is fed to the 5/2-way valve and generates signal "**b**" which passes through the **OR** and afferwards signal "**a**" to the **AND**. In the presence of signal "**b**" generated by the switch **b0**, output **X** which becomes the start signal, is obtained. If the 5/2-way valve (**C.S./A.C.**) is reverted to Single Cycle, the sequence stops once the last phase is completed.

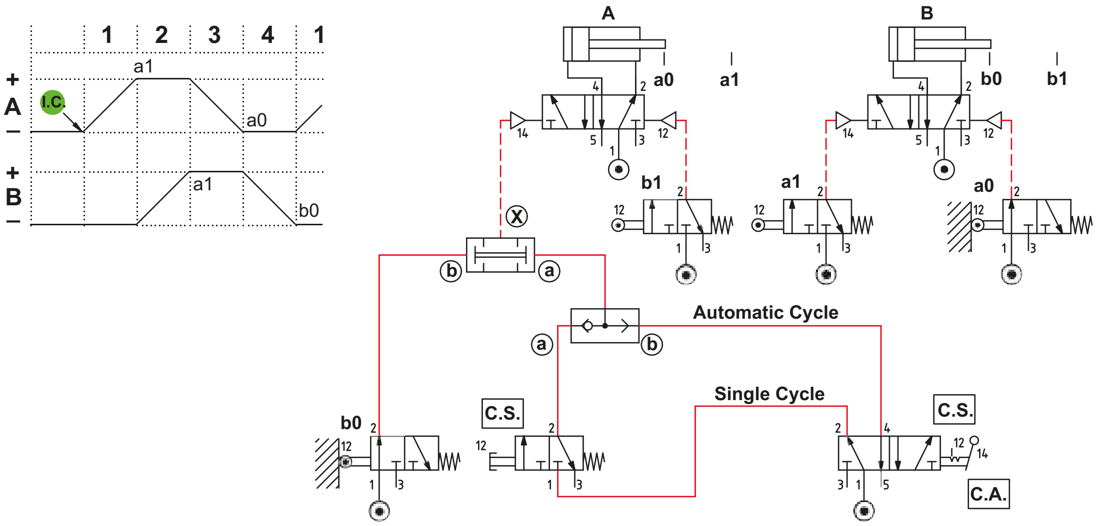


Fig. 59

Emergency command

An Emergency situation usually refers to any unforeseen and potentially dangerous situation, which requires immediate action to ensure the safety of the machine operators.

This command can be divided into the following:
Stop during cycle for example, either interrupting the movement of the piston rod/piston which then remains at the position which it has reached, or allowing it to reach the end position thereby preventing the continuation of the cycle.
General Stop there is no specific rule for this type of stop. The system designer will select the most suitable parameters, i.e. repositioning the piston rod/piston of the various cylinders to their respective initial positions, allow them to reach the end position of pneumatically feed some areas of the plant or exhaust it partially, completely, or vice versa.

The emergency command **EM** must be both accessible and visible. Comprised of a 3/2-way NC valve, the actuating device generally requires:

- a large contact surface for ease of operation (mushroom button),
- highly visible colour (red),
- a mechanical self - latching mechanism constructed so the cycle will only resume once the operator confirms adequate safety requirements have been re-established.

Figure 60
Stop during cycle and restart from the same phase
The emergency stop EM valve is connected to the pilot port of a monostable 3/2-way NO valve that provides compressed air to all limit switches. In the presence of this pilot signal from the EM valve, the 3/2-way valve shuts off the passage interrupting the air supply to the limit switches preventing the continuation of the cycle.
The piston rod/piston of the cylinder stops upon reaching the end position. When the air supply is restored to the limit switches, the sequence resumes from its stopped position.

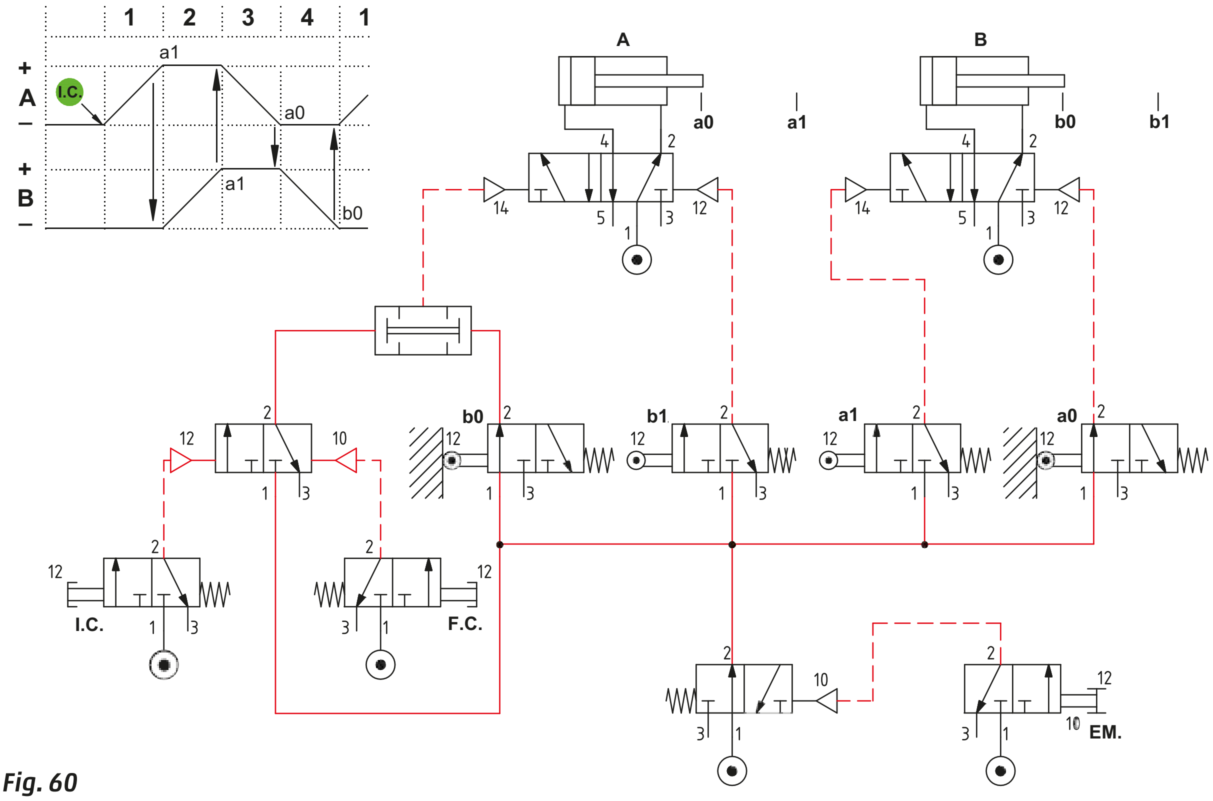


Fig. 60

Figure 61
A variation of the previous condition
The EM valve is connected to the pilot port of a pneumatically operated monostable 5/2-way valve, which, in rest position, feeds the limit switches and the 3/2-way valve thus enabling the sequence.
When the EM valve is actuated, the pressure supply of the limit switches is interrupted, preventing the continuation of the cycle, as in the previous example. Upon resetting the EM valve, the cycle restarts from the phase where it was interrupted as in the previous case. With this variation, one can decide whether to resume from the stopped position, or re-start from the first phase by pushing the **RESET** button.
When the EM valve is actuated, the **RESET** valve is fed with compressed air and as a result of its operation using the **OR** functions, it is possible to return the piston rod/piston of the actuators to their respective starting position.

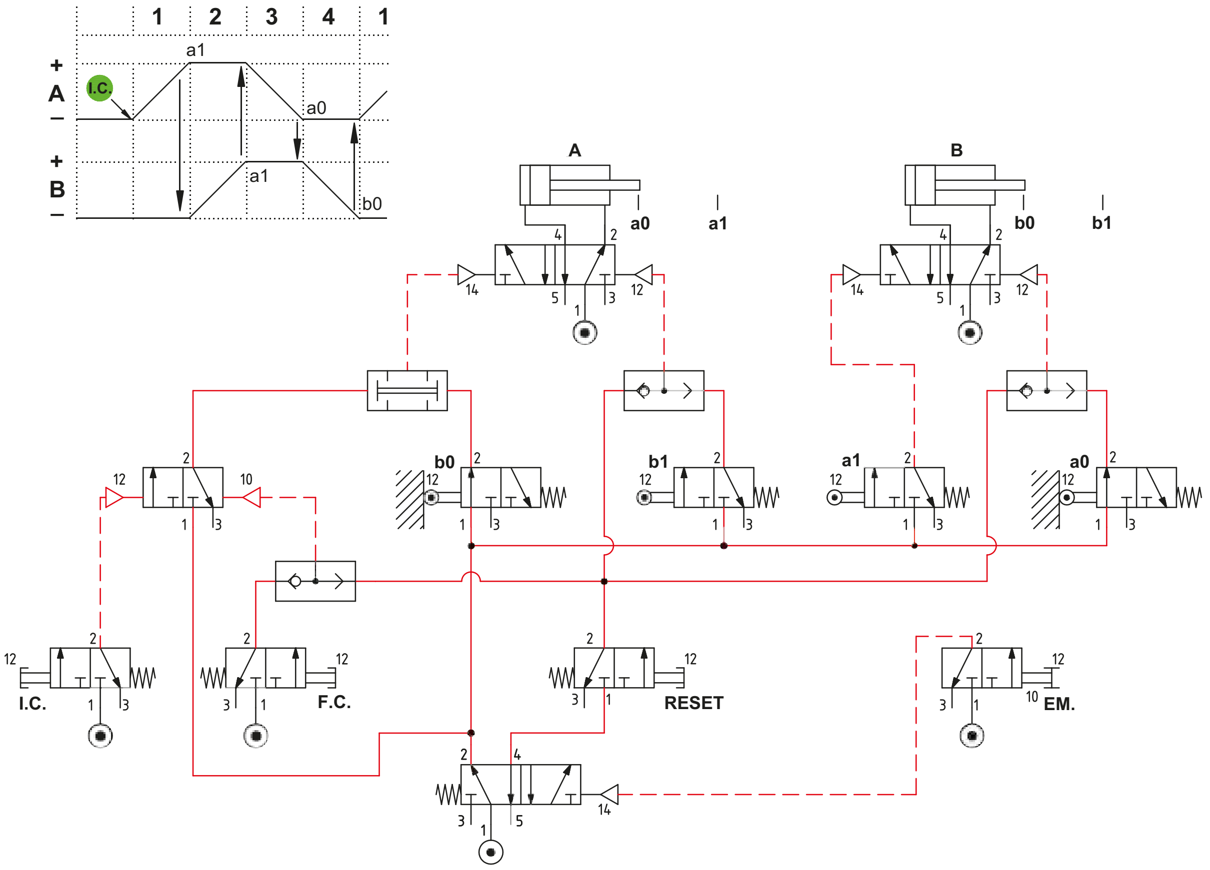


Fig. 61

The EM command does not always generate the same effect; based on the circuit in which it is engaged, it is possible for the piston rod/piston of the actuator to reach the end position, in contrast to situations where it is preferable to return to the cycle start position or an alternative position. In this example you break the cycle and bring the cylinders to the start cycle position, in a sequence that avoids any eventual mechanical interference.

We develop the following sequence:

A + / B – / C + / A – / B + / C –

Figure 62
Required condition in the case of EM: the piston rod/piston of cylinders **A** and **B** must be the first to return, and only upon the arrival of their respective end positions is the piston rod/piston of cylinder **C** able to move.

Analysis of the circuit:
when the system is stationary the pilot port of the 5/2-way valve is connected to the outlet of the EM valve, this 5/2-way valve has outlet 2 active and feeds the 3/2-way valve, which in this phase is closed. By operating the **I.C.** button, and assuming no other commands intervene, the 3/2-way opens and the cycle starts.
While operating the **F.C.** button the 3/2-way valve closes, the limit switch **c0** is no longer fed, the sequence reaches the last phase and stops. Activating the EM will pilot the 5/2-way valve which exhausts outlet 2, interrupting the air supply of the 3/2-way valve while pressurizing outlet 4, which, via the **OR** function:

- places the 3/2-way valve in the closed position,
- operates the valve in order to make the piston rod/piston of cylinder **A** return,
- operates the valve in order to make the piston rod/piston of cylinder **B** return.

In the presence of the output signal from the limit switches **a0** and **b1** and due to the effect of the **AND** function, we have confirmation that both cylinders have reached the desired position and it is possible to operate the valve in order to allow the return of the piston rod/piston of cylinder **C**.

By releasing the mechanical latch of the EM valve, air supply is restored to the 3/2-way valve and the sequence can be restarted with the **I.C.** command.

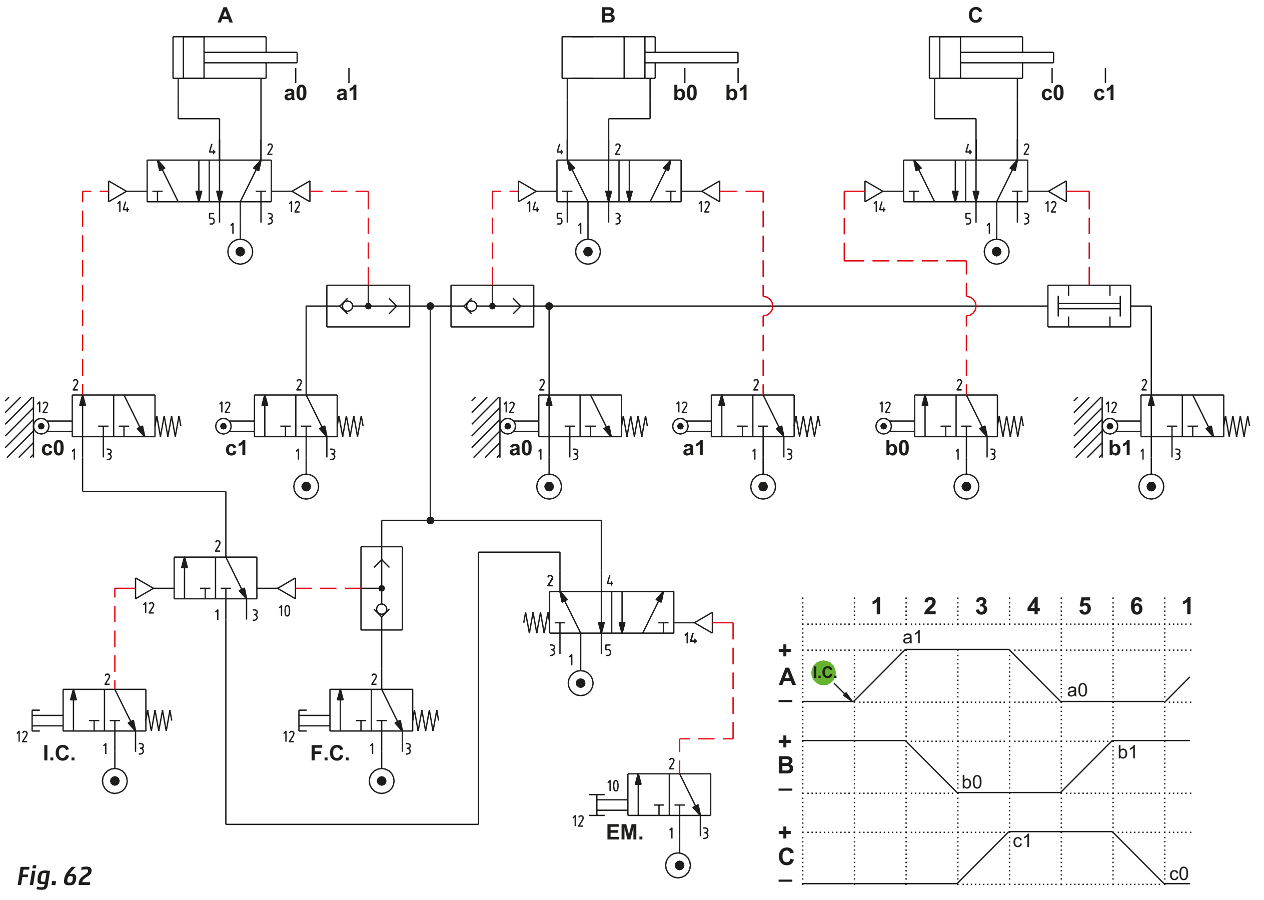


Fig. 62

Development of a sequence

Through a safety door, it is possible to reach the inside of a mechanical structure where an object can be positioned in order to be clamped and then stamped.

The conditions required to start the cycle are: the safety door is closed and the **I.C.** button remains actuated by the operator until the marking operation is executed. Should the door be opened or the button released, the piston rod/piston of the two cylinders must return to their initial position.

Figure 63
Pos. 1: the component is inserted into the mechanical structure and the safety door is closed.
Pos. 2: by pressing the **I.C.** button the piston rod/piston of cylinder **A** used in the blocking operation executes the positive stroke.
Pos. 3: upon reaching the positive end position, and clamping the component, the marking operation with cylinder **B** can begin.
Pos. 4: once the marking operation is complete, the piston rod/piston of the two cylinders return to their initial positions. At this stage it is possible to release the **I.C.** button, open the door, remove the marked item and insert the new one.

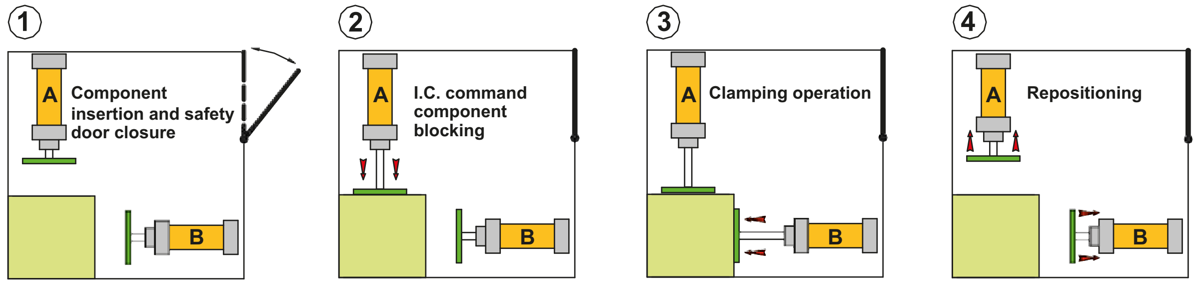


Fig. 63

Flow diagram and designing a pneumatic circuit

A flow diagram based on the literal description of the sequence, can be constructed once the cycle and the safety conditions are established. **S** represents the valve which detects the closure of the safety door and **I.C.** represents the Start Cycle.

Figure 64
Pos. 1: the cycle takes place in three Phases:

Phase 1	I.C. ∗ S = **A +**
Phase 2	I.C. ∗ S ∗ a1 = **B +**
Phase 3	I.C. ∗ S ∗ a1 ∗ b1 = **A – B –**

Pos. 2: the safety conditions indicated in the previous paragraph require that in the absence of the **I.C.** command or opening of the safety door, the piston rod/piston of the cylinders should return to their initial position.
The easiest way to achieve this is to control the two cylinders with monostable 5/2-way valves, which r in the absence of the pilot signal, are repositioned, inverting the outlets guaranteeing the required conditions. The strokes of the two cylinders are variable, as the dimensions of the component are not defined, therefore it is not possible to use limit switches. To detect the position of the cylinders, logical **NOT** elements are used. As common practice, the valves and cylinders are represented in the circuit in the positions they assume in rest condition. The connection of the two monostable 5/2-way valves to the network ensure that in the absence of the pilot signal, the piston rod/piston of both cylinders are at the negative end position. Valve **S** is not connected at this moment.
Pos. 3: positive stroke of the piston rod/piston of the cylinder **A**. The safety prerequisite necessary to start the cycle requires the presence of the signal coming from both the **I.C.** valve and the **S** valve. In order to satisfy this condition, we introduce the logical **AND** function, whose output, determined by the presence of the two inputs (**I.C.** and **S**), operates the main valve of cylinder **A**. The **I.C.** valve is a monostable 5/2-way valve operated by a button fed directly from the compressed air network and outlet 4 which is inactive and connected to the inlet of the **AND** element. The limit switch **S** is a mechanically operated 3/2-way valve NC whose outlet 2 is connected to the other inlet of the **AND** element.
Pos. 4: introduction of the logical function **NOT** for stroke **A+**. The **NOT** function receives the pilot signal only when the cylinder **A** has almost completely exhausted the compressed air from the front chamber confirming that it has terminated its stroke against the component. The output of the NOT **a1** is connected to pilot port 14 of the main valve of cylinder **B** which through its changeover allows the positive stroke.

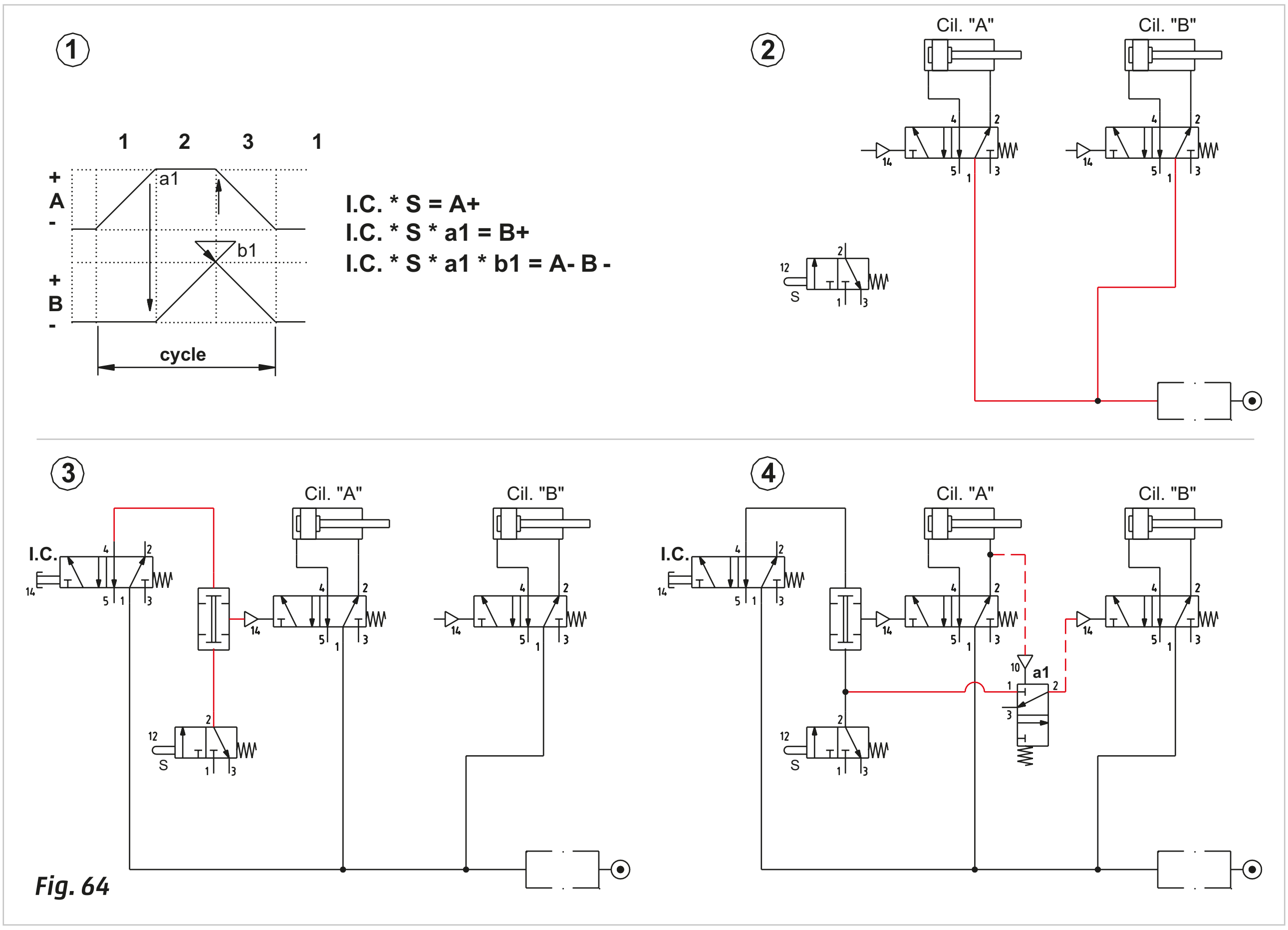


Fig. 64

Figure 65

Pos. 1: the piston rod/ piston of cylinder **B** has completed the positive stroke.
As with cylinder **A**, cylinder **B** also has a variable stroke and in this case a NOT function (**b1**) is also used to ensure that the piston rod/piston has reached the component. This function is operated by the pressure in the front chamber of cylinder **B** and fed from the output of the NOT element connected to cylinder **A**.

Pos. 2: return of the piston rod/piston of cylinders **A** and **B**.
Once the **B +** movement is completed, the NOT element **b1** indicates that the positive end position has been reached and sends the operating command to the 3/2-way memory valve, which closes the output by changing over.
This implies that the **S** valve is no longer fed, and consequently neither are the operation of the **AND** function nor the air supply of the NOT **a1**. The piston rod/piston of cylinders **A** and **B** return to the initial position.

Pos. 3: release of the **I.C.** button.
The eventual release of the **I.C.** button or the **S** valve during the cycle closes the outlet of the **AND** function, the valve which controls cylinder **A** reassumes the position defined by the spring. The piston rod/piston of cylinder **A** returns to the negative end position; receiving no output signal from the NOT function, the valve which controls cylinder **B** is also repositioned. The cycle has not completed successfully. Only in this phase it is possible to release the **I.C.** button, which, by exchanging outlet 4 and 2, repositions the 3/2-way memory valve in the open position, reactivating the air supply to the **S** valve. This creates a condition that requires the operator to release the button before the next cycle. The operator, now with hands free, may open the safety hatch, take out the marked component component and insert a new component.

Pos. 4: final verification.
Upon activation and release of the **I.C.** button with a closed door, **S** is activated.
At any stage of the sequence when the **I.C.** button is released, the piston rod/piston of the cylinders execute their negative strokes. With the subsequent activation of the **I.C.** button, the cycle resumes from Phase 1.

I.C. button is pressed and the safety door is open, **S** is disabled. If the door is opened during the positive stroke of the piston rod/piston, the valve **S** interrupts the air supply to the NOT element and the piston rod/piston of cylinders **A** and **B** return. With the safety door open, the command of the **I.C.** button alone does not enable the start of the cycle.

With the **I.C.** button released and the safety door closed, **S i**s activated.
The required start cycle conditions have not been met.

The required conditions have been respected.

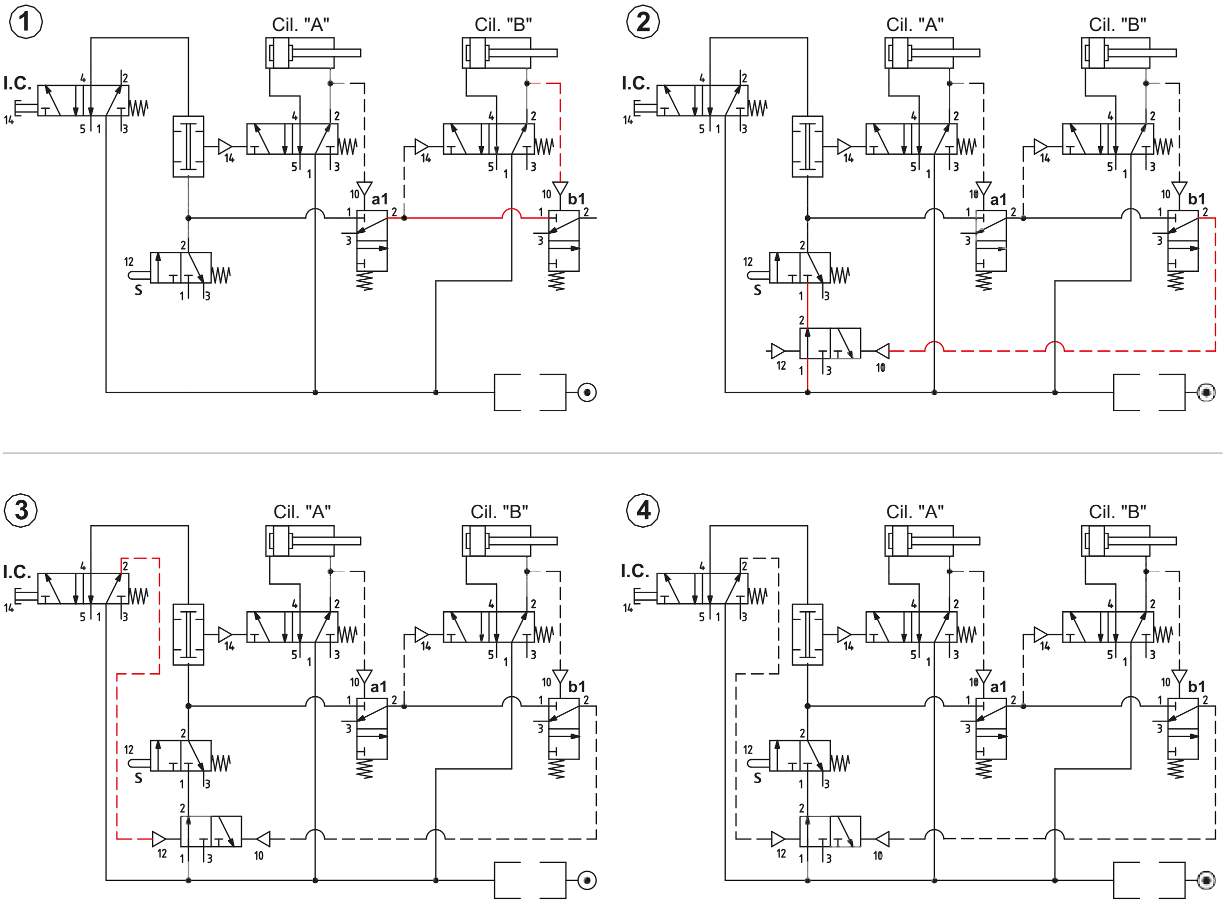


Fig. 65

Movement of multiple cylinders

In this example, the cycle includes three cylinders whose movements are defined by the following conditions:

Figure 66

Pos. 1: verification the bar is at the input and the exit chute is free	
Pos. 2: introduction of the bar in the lift **A +**	**Phase 1**
Pos. 3: bar is lifted **B –**	**Phase 2**
Pos. 4: ejection of the bar towards the exit chute **C +**	**Phase 3**
Pos. 5: return of the pusher cylinder **A –**	**Phase 4**
Pos. 6: return of the ejector and lifting cylinders **B + C –**	**Phase 5**

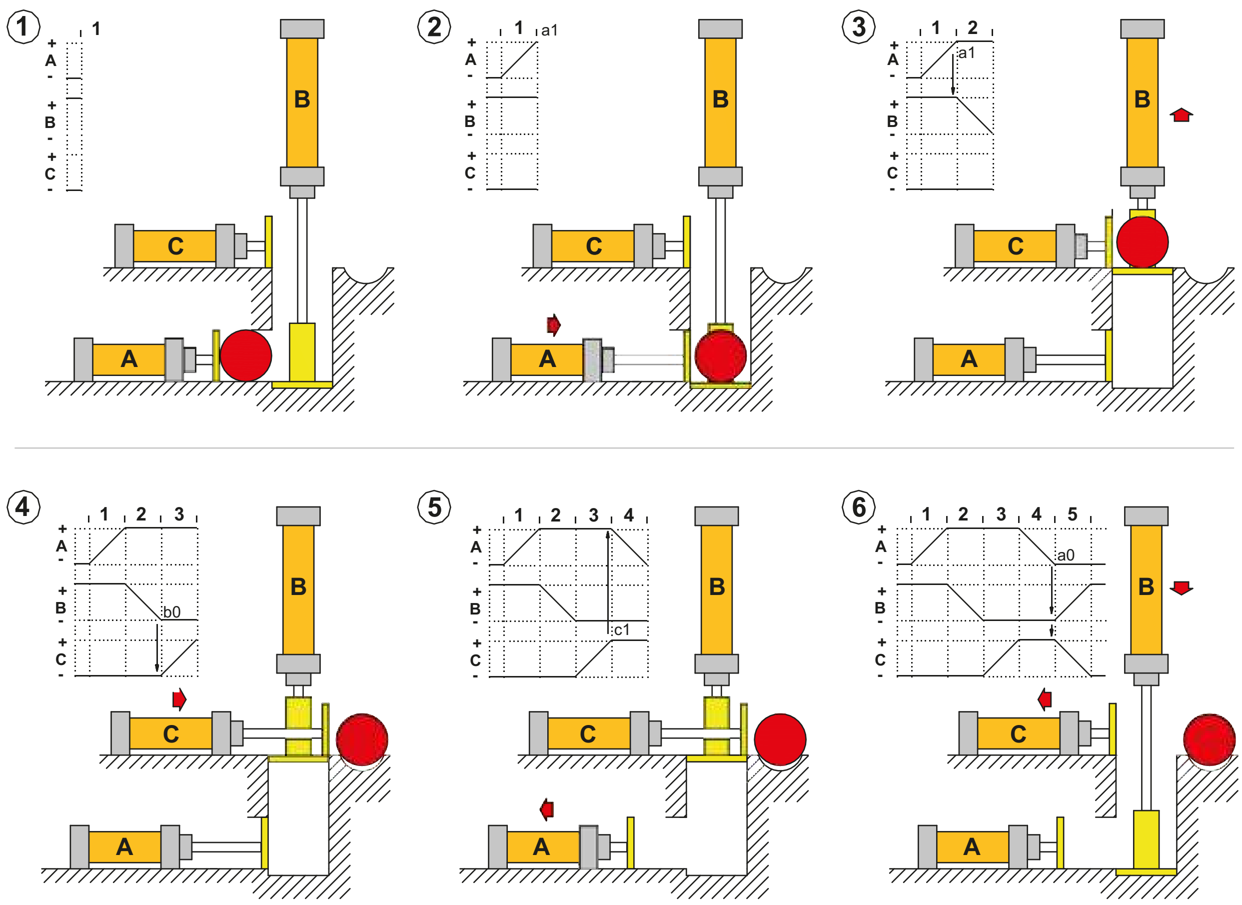


Fig. 66

Unlike in the previous example, mechanically operated limit switches are used to detect the position of the cylinders. The start command is provided through a Start Cycle **I.C.** valve. In addition to verifying the presence of the bar, the piston rod/piston of both cylinders **B** and **C** must have completed their respective strokes during the starting phase.

It is necessary to consider whether the signal is continuous or an impulse signal when selecting the type of main valve. Unlike a monostable valve, the choice of a bistable valve prevents the continuation of the pilot signal. The cylinders and their respective limit switches are represented in their initial state, and the connection lines from the main valves to the cylinders are drawn. The connections and lines regarding the limit switches shall be drawn so as to avoid intersecting connecting lines as much as possible.

Figure 67

Introduction of the bar in the lift   I.C. ∗ b1 ∗ c0 = **A +**   **Phase 1**

The action on the **I.C.** valve generates a signal that crosses the limit switches **b1** and **c0**, which in this phase are operational and therefore open. This signal, connected to pilot port 14 of the main valve of cylinder **A**, initiates the positive stroke and the completion of phase **A +**. In the absence of an air passage at the **I.C.** , **b1** or **c0**, the cycle cannot start.

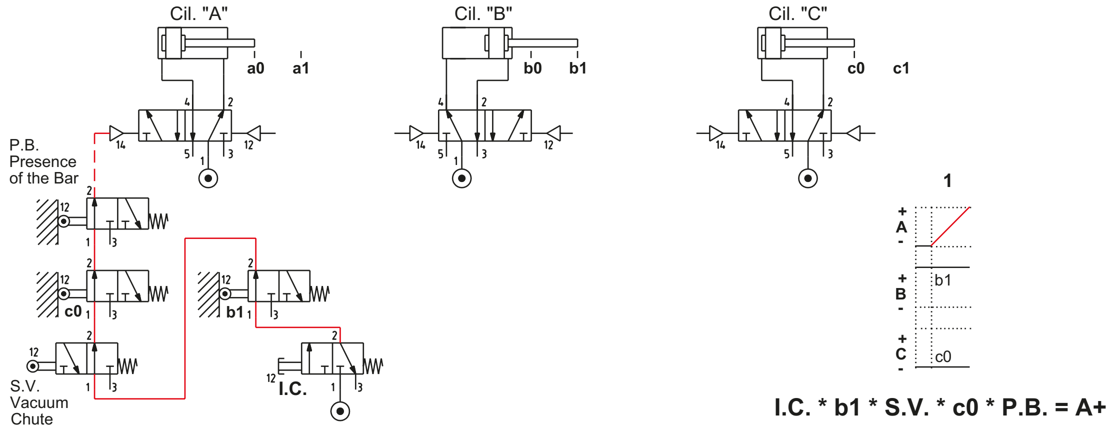


Fig. 67

Figure 68

Lifting of the bar **a1** = **B – Phase 2**

Once limit switch **a1** is reached, a signal is generated; this signal, if sent to pilot port 12 of the main valve of cylinder **B**, dictates the return of the piston rod/piston and the completion of Phase **B –**.

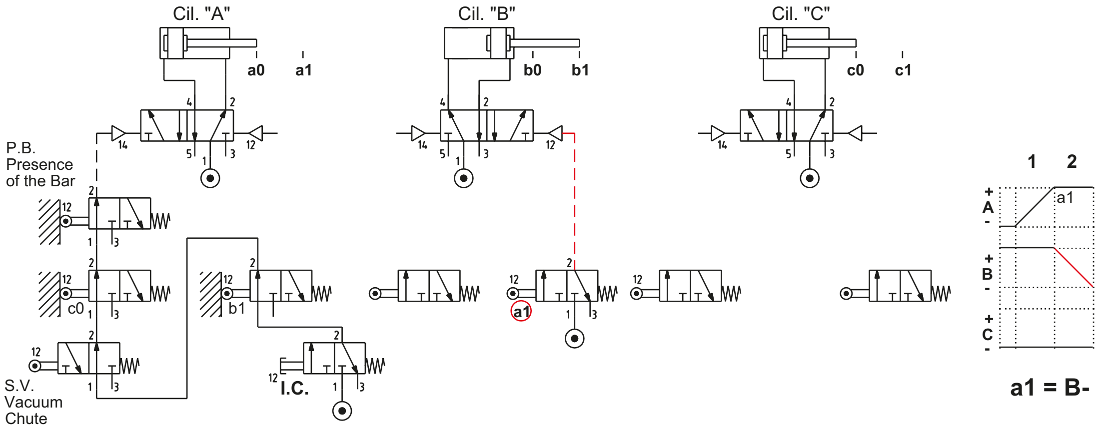


Fig. 68

Figure 69

Ejection of the bar towards the exit chute **b0** = **C + Phase 3**

Once limit switch **b0** is reached, a signal is generated; this signal, if sent to pilot port 14 of the main valve of cylinder **C**, dictates the positive stroke of the piston rod/piston and the completion of Phase **C +**.

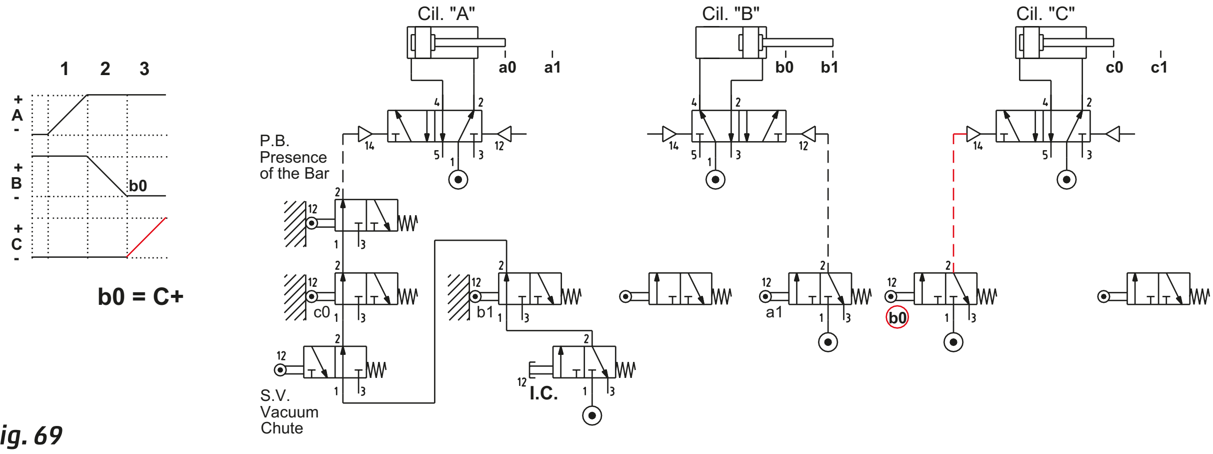


Fig. 69

Figure 70

Return of the feeder cylinder **c1** = **A –** **Phase 4**

Once limit switch **c1** is reached, a signal is generated; this signal, if sent to pilot port 12 of the main valve of cylinder **A**, dictates the return of the piston rod/piston and the completion of Phase **A –**. Pilot signal 12 can switch the valve of cylinder **A**, as the positions of the limit switches **b1** and **c0** are altered and pilot signal 14 is absent.

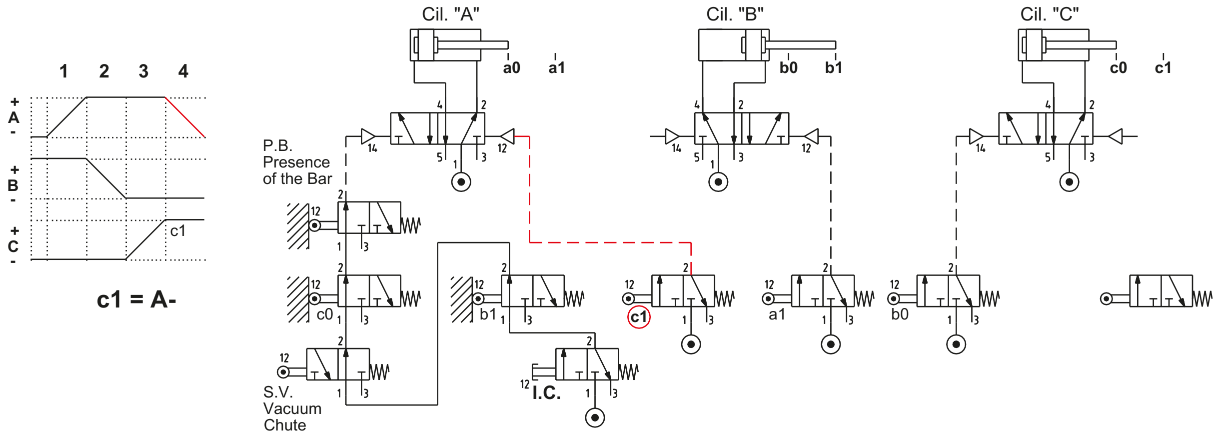


Fig. 70

Figure 71

Return of the ejecting- and lifting cylinder **a0** = **B + C –** **Phase 5**

With the operation of limit switch **a0**, a signal is generated; this signal, if sent to pilot port 14 of the main valves of cylinders **B** and **C** (which, by changing over), allow the return of the piston rod/pistons of the two cylinders to the cycle start positions, i.e. **B +** and **C –**. The limit switch **a0** is represented as actuated, as in the beginning of a cycle. The changing over of the main valves is assured by the duration of the signal present throughout the entire Phase 5.
The position of the actuators is the same as in the initial condition, only with the consent of the **I.C.** valve and the limit switches **b1** and **c0** activated the cycle can start.

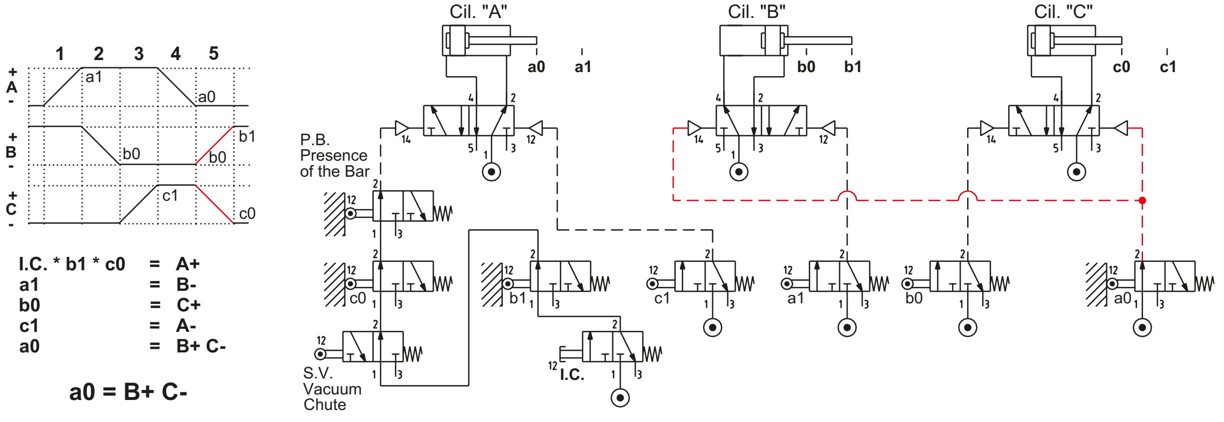


Fig. 71

Figure 72

This circuit uses **bistable** main valves as the main valve of the cylinder **A** cannot be monostable since pilot signal 14 is influenced by the presence of the limit switches **b1**, **c0** and the **I.C.** command. Also the main valve of the cylinder **B** cannot be monostable in fact the limit switch **a1** which generates the negative stroke remains operational until the end of Phase 3, and not piloting the valve anymore, it would more the cylinder, however its position must be maintained also during Phase 4. Only the main valve of cylinder **C** may be monostable.

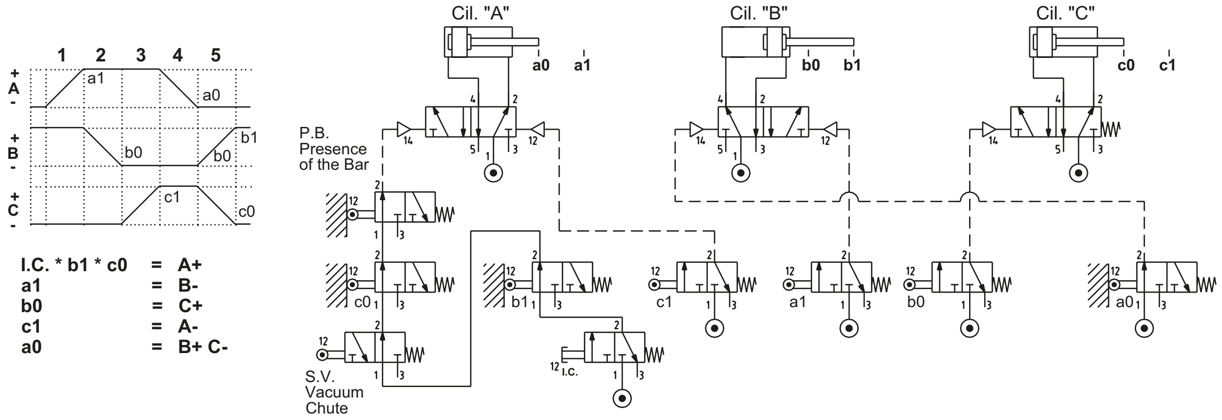


Fig. 72

Identification of blocking signals

Upon examining the previous sequences, we observed that the signals generated from the limit switches did not always guarantee the continuity of the cycle. The three types of signals are: **immediate**, **prolonged** and **blocking**. The blocking signals are those signals which impede the continuation of the cycle.

Figure 73
We examine one of the previous sequences:

A + / B + / C + / A – / C – / B –
1 2 3 4 5 6

When constructing the sequence; the blocking signals and the destination of their respective output signals must be identified. To do this we represent them individually.

Signal **a1**: what is the origin? The limit switch - activated when position **A +** has been reached.
What is its function? To generate the positive stroke of cylinder **B** through the main valve.
The signal disappears during phase 4, it does not obstruct the return of the cylinder **B** during Phase 6.
The signal is **prolonged** as it is present during Phases 2 and 3.
Signal **b1**: what is the origin? The limit switch, activated when position **B +** has been reached.
What is its function? To generate the positive stroke of cylinder **C** through the main valve.
The signal is still present during phase 5 when cylinder **C** should be returning.
This is a **blocking** signal (as it obstructs the return of cylinder **C**).
Signal **c1**: what is the origin? The limit switch, activated when position **C +** has been reached.
What is its function? To generate the negative stroke of cylinder **A** via the main valve.
The signal disappears during phase 5; it does not obstruct the return of cylinder **A** during Phase 4.
The signal is **prolonged** as it is present during Phase 4.
Signal **a0**: what is the origin? The limit switch, activated when position **A –** has been reached.
What is its function? To generate the negative stroke of cylinder **C** via the main valve.
The signal disappears during phase 1; it does not obstruct the positive stroke of cylinder **C**.
The signal is **prolonged** as it is present during Phases 5 and 6.
Signal **c0**: what is the origin? The limit switch, activated when position **C –** has been reached
What is its function? To generate the negative stroke of cylinder **B** via the main valve.
The signal is present during both stroke lengths of cylinder **B**.
This is a **blocking** signal.
Signal **b0**: what is the origin? It is the last received signal and it is generated at the end of each cycle when the cylinder **B** terminates the negative stroke.
What is its function? To generate the positive stroke of the cylinder **A** through the main valve.
The signal disappears during Phase 2; it does not obstruct the return of cylinder **A**.
The signal is **prolonged**.

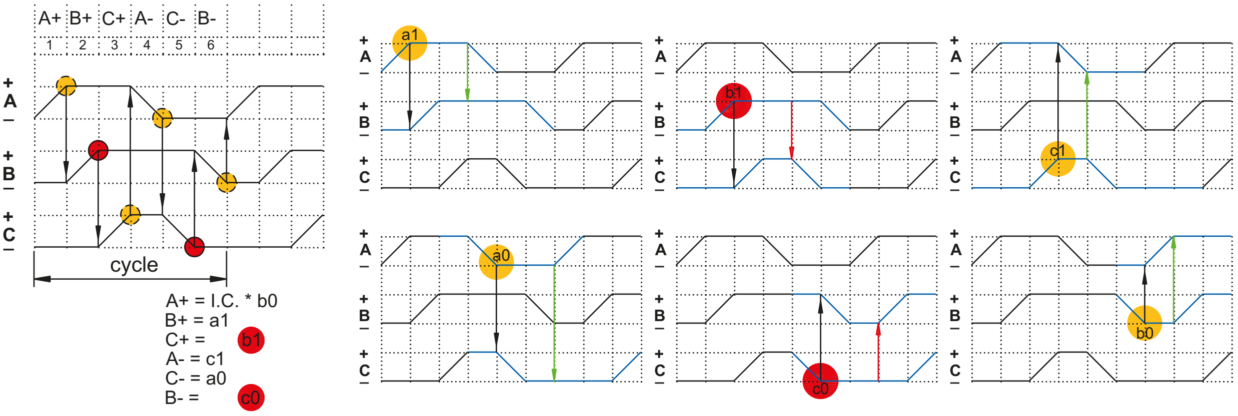


Fig. 73

Figure 74
Similarly, for the following sequence:

A +   /   B +   /   C +   /   C –   /   B –   /   A –
1   2   3   4   5   6

Signal **a1**: **blocking** as it is active during Phase 5, when cylinder **B** must return
Signal **b1**: **blocking** as it is active during Phase 4 when cylinder **C** must return
Signal **c1**: **immediate** as it only serves cylinder **C** on its return
Signal **a0**: **blocking** as it is active during Phase 2, when cylinder **B** must execute its positive stroke
Signal **c0**: **blocking** as it is active during Phase 1, when cylinder **A** must execute its positive stroke
Signal **b0**: **immediate** as it is the last received signal, and it is generated at the end of the cycle.
It confirms the start of the cycle.

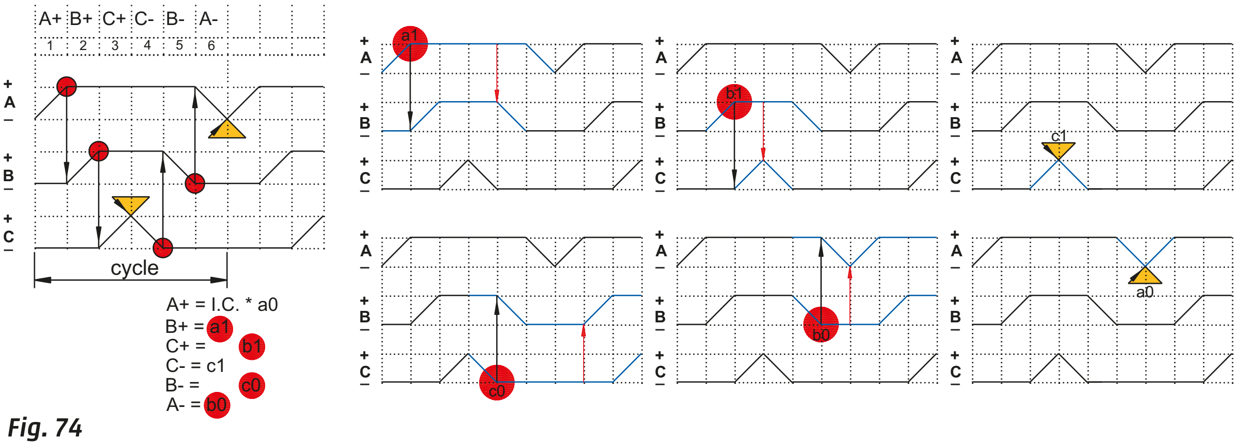


Fig. 74

Relationships between signals and movements are depicted on flow diagrams, where the signal becomes a **blocking** signal it will be highlighted in red.

Techniques to eliminate blocking signals

The signals generated by the limit switches remain active for all the time they remain actuated and enable progression through the various stages of the sequence. However the long duration of these signals can present a problem in those situations where they prevent the repositioning of the device upon which they are acting; in this case they are defined as **blocking** signals.
These signals must be identified on a schematic flow chart to avoid possible "conflicts" which could obstruct the continuation of the cycle.

To eliminate the blocking signals any of the following may be applied:

- remove the mechanical control which operates the limit switch
- control the air supply of the limit switch
- control the signal they generate.

Consider the following sequence:

A – / B + / B – / A +
1 2 3 4

Figure 75
Drawing the flowchart.

Phase 1 presence of the **I.C.** command and limit switch **a1**	**A –**	**I.C. ✻ a1** = **A –**
Phase 2 presence of limit switch **a0**	**B +**	**a0** = **B +**
Phase 3 presence of limit switch **b1**	**B –**	**b1** = **B –**
Phase 4 presence of limit switch **b0**	**A +**	**b0** = **A +**

Phase 1: **A –**
To activate "start" (of movement) requires the output of the limit switch **a1** to be actuated together with the Start Cycle command **I.C.** (Inizio Ciclo). To accomplish this, either place two valves in series or their two respective outputs in a logic AND element. The piston rod/piston of cylinder **A** completes the negative stroke.

A – = I.C. ✻ a1

Phase 2: **B +**
Once limit switch **a0** has been reached by the piston rod/piston of cylinder **A**, a signal is transmitted enabling the positive stroke of the piston rod /piston of cylinder **B**.

B + = a0

Fase 3: **B –**
Once limit switch **b1** has been reached by the piston rod/piston of cylinder **B**, a signal is transmitted enabling the negative stroke of the piston rod/piston of cylinder **B**.
If the actuating device of the limit switch were to be a bidirectional roller lever, the cycle would stop. The command given by limit switch **a0** that generates the movement of **B +** will still be present on the valve of cylinder **B**.
Consequently, the output signal from limit switch **b1** will be unable to change the state of the main valve to execute movement **B –**. In this case the signal **a0** is **blocking** and therefore highlighted by a red circle.

B – = b1

Fase 4: **A +**
Presuming we have resolved the problem of the previous step.
Once the piston rod/piston has reached the limit switch **b0** of cylinder **B**, a signal is transmitted enabling the positive stroke of the piston rod/piston of cylinder **A**. The cycle has completed, but it is unable to restart as the output signal from limit switch **b0** is **blocking** the movement of cylinder **A**. The blocking signal is highlighted by a red circle as in the previous case.

A + = b0

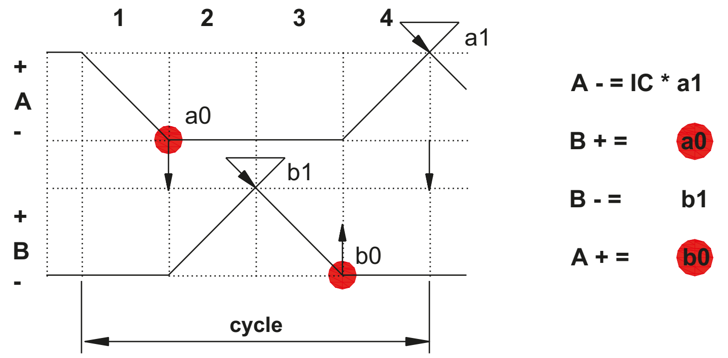


Fig. 75

Figure 76

Now we replace the actuator limit switches **a0** and **b0** with a undirectional roller lever.

Pos. 1: the switch can only be actuated from one direction. Due to effect of the "knee" joint, the drive from the opposite side causes the lever to flex and the valve does not generate any signal.

It is important that this valve remains non-actuated at the end position of the cylinder and therefore must be installed so that the control cam releases the actuating device in this position. The duration of the output signal will depend on the length of the cam and the speed of the cylinder. A cam that is too short or a cylinder whose speed is too high could generate an output signal whose very short duration could be insufficient to command the changeover of the main valve.

Pos. 2: pneumatic circuit using the limit switch with a unidirectional roller lever. In this case the limit switches **a0** and **b0** are no longer blocking signals - the cycle is not interrupted.

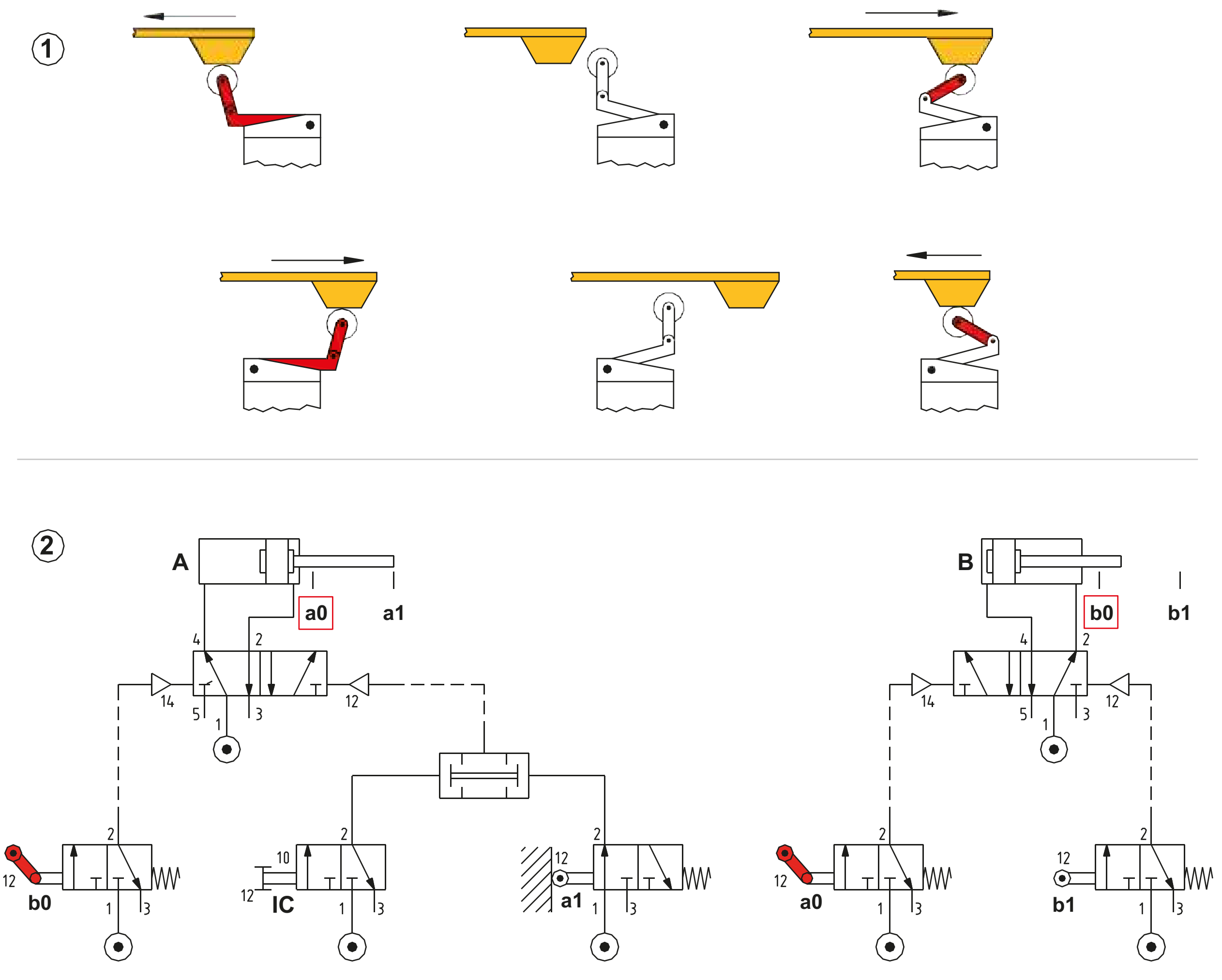


Fig. 76

In the previous paragraph we eliminated the blocking signals by changing the type of limit switch. We now proceed with the alternative solutions, such as **controlling the air supply**.

This control can be achieved by the following two techniques:
- the technique of the connections
- the technique of the memories.

The Technique of the Connections

Consider the sequence

A +	/	B +	/	A –	/	C –	/	B –	/	C +
1		2		3		4		5		6

Figure 77
While preparing the flow diagram, we observe the **blocking** signals generated by:
- limit switch **c1**, which indicates the positive position of the piston rod/piston of the cylinder **C** and combined with the other signals, enables the beginning of the cycle with the start of movement **A +**; it remains active also during Phase 3 and blocks movement **A –**.
- limit switch **a0**, indicates the negative position of the piston rod/piston of cylinder **A** and enables the **C –** movement. It remains active also during phase 6 and blocks movement **C +**.

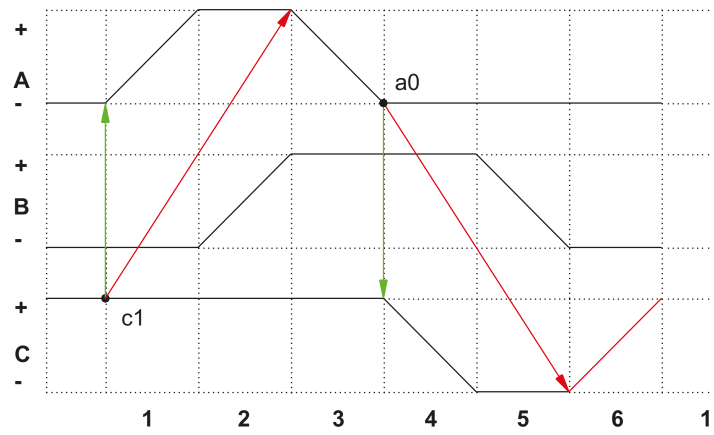


Fig. 77

We analyze the individual phases of the sequence, determining the possibility of, and methods for, eliminating the blocking signals.

Figure 78
Phase 1: **A +**
The signal from limit switch **a0** which enables the start of cylinder **C**, is a blocking signal, as it remains active during both strokes of the cylinder. This can be avoided by feeding it through limit switch **b0**, which remains until the end of Phase 1. The limit switch **a0** re-activates at the end of phase 5 when the piston rod/piston of cylinder **B** actuates limit switch **b0**.

A + = b0 * c1 * I.C.

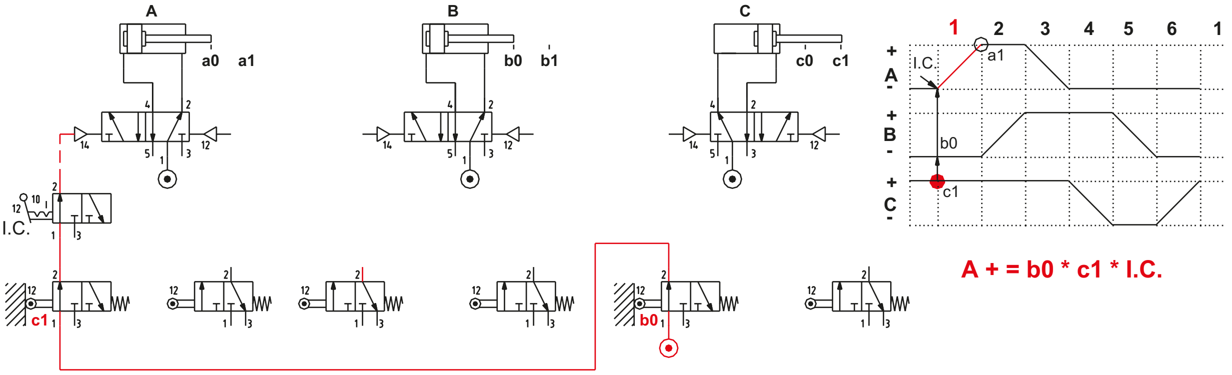


Fig. 78

Figure 79

Phase 2: **B +**

Limit switch **a1**, which determines the start of cylinder **B**, can be fed from the compressed air network as its operation ends after Phase 3.

B + = a1

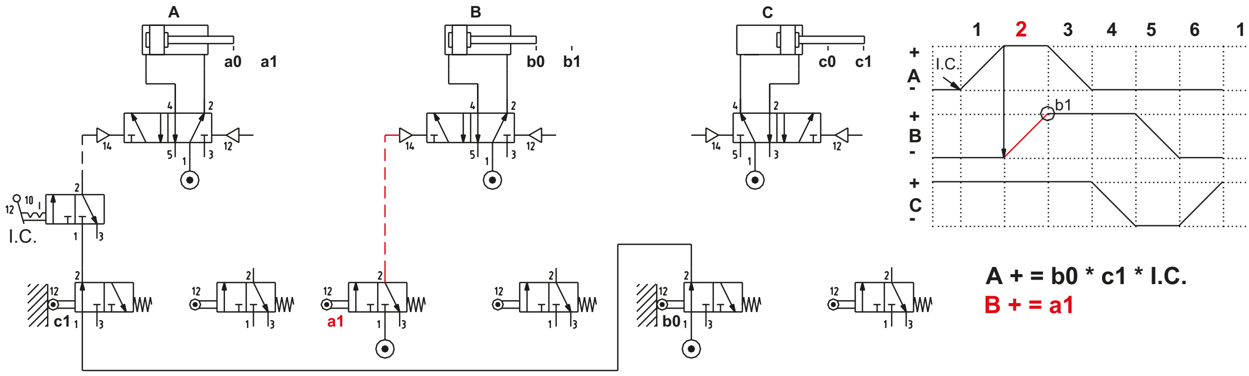


Fig. 79

Figure 80

Phase 3: **A –**

The limit switch **b1**, which enables the negative stroke of the piston rod/piston of cylinder **A**, can be fed from the compressed air network as the positive stroke only occurs in the subsequent cycle when limit switch **b1** is not active.

A – = b1

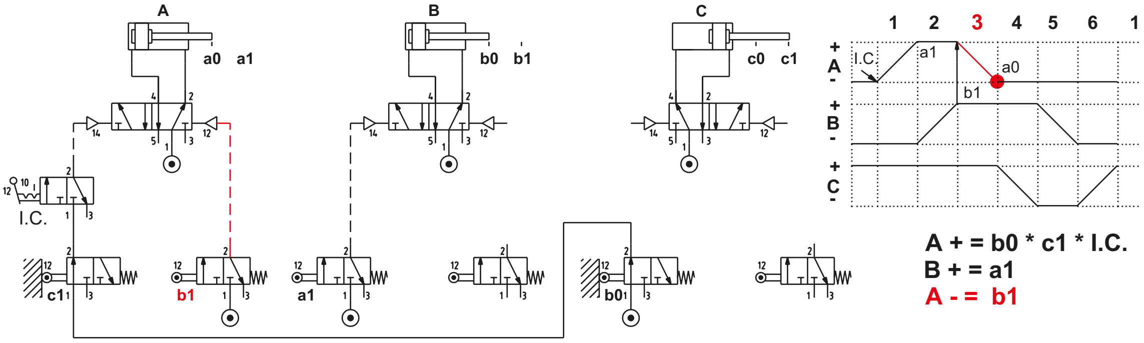


Fig. 80

Figure 81

Phase 4: **C –**

The limit switch **a0**, which enables the negative stroke of the piston rod/piston of cylinder **C**, can be fed by the output of limit switch **b1** as:

- the air supply coming from **b1** is present prior to the activation of **a0**.
- limit switch **a0** does not present itself for a second time during the sequence.
- limit switch **b1** is no longer active in the presence of **C +**.

C – = b1 ⁎ a0

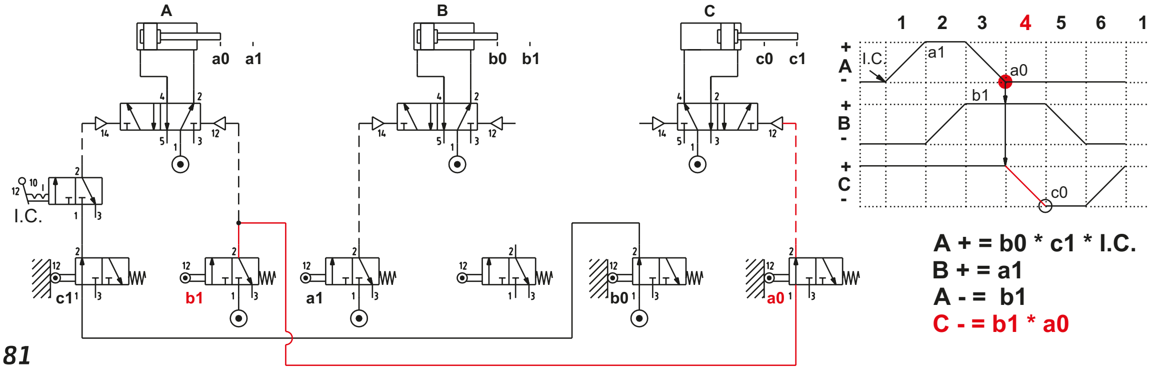


Fig. 81

Figure 82
Phase 5: **B –**
The limit switch **c0**, which permits the negative stroke of the piston rod/piston of cylinder **B**, can be fed from the compressed air network as the positive stroke only occurs in the following cycle.

B – = c0

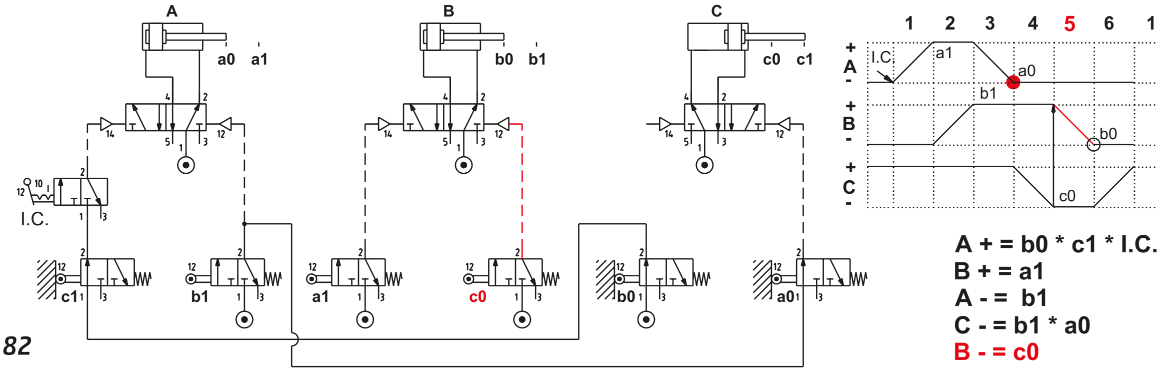


Fig. 82

Figure 83
Phase 6: **C +**
Upon termination of the negative stroke, the piston rod/piston of cylinder **B** actuates limit switch **b0**, which feeds limit switch **c1**, and consequently the **I.C.** command and the pilot signal of the main valve of cylinder **C** for its positive stroke.

C + = b0

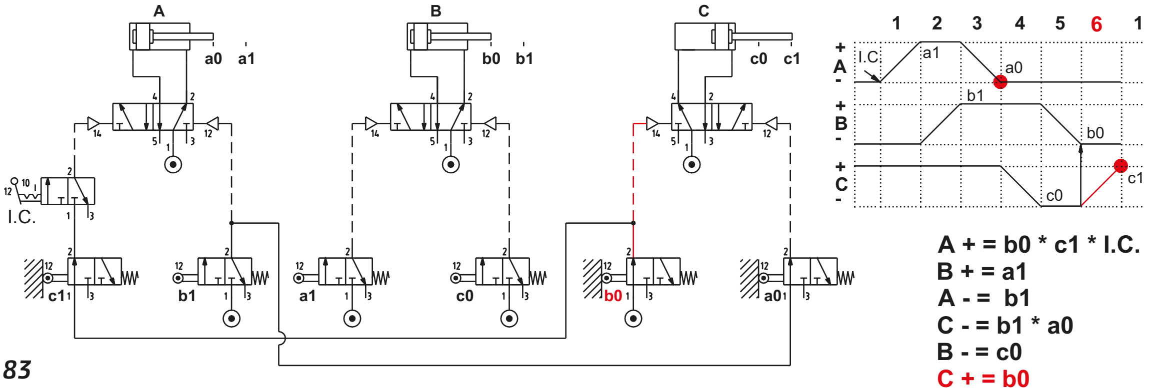


Fig. 83

The sequence has finished and returns to the initial state: limit switches **b0** and **c1** are activated and their outputs active as they are fed by the compressed air network. Limit switch **a0** is activated but not powered. The activation of the **I.C.** command enables the sequence to restart.

Memories technique
Using this technique it is possible to control the air supply of the limit switches.
We use the same sequence as in the previous section.

A +	/	B +	/	A –	/	C –	/	B –	/	C +
1		2		3		4		5		6

The limit switches that generate blocking signals as stated above, are **a0** and **c1**.
Once the blocking signals have been identified, the sequence is divided into groups. Each group comprises a set of letters, which represent their respective cylinders, within the group the same letter **must not appear more than once**.

By subdividing groups in the sequence we have:

A + / B + / A – / C – / B – / C +

A + / B + / C + the limit switches of this group will be fed by a line labelled **U1**

A – / C – / B – the limit switches of this group will be fed by a line labelled **U2**

A 5/2-way memory valve has been introduced to the circuit. The respective outlets **U1** and **U2**, alternating feed the limit switches of the cylinders of their respective groups.

Figure 84
Phase 1: **A +**
The last movement was the piston rod/piston of cylinder **C** activating limit switch **c1**.
This limit switch is fed by **Line U1** in this active Phase, its output supplies air to the **I.C.** command which permits the piloting of the main valve of cylinder **A** and the positive stroke of its piston rod/piston.

U1 * c1 * I.C. = A +

Phase 2: **B +**
Having advanced to the positive end position, limit switch **a1** is activated and fed by **Line U1**. Its outlet allows the piloting of the main valve of cylinder **B** and the positive stroke of its piston rod/piston.

U1 * a1 = B +

Phase 3: **A –**
As per the subdivision of the groups, the last operation of the first group is reaching position **B +**. The limit switch **b1** which detects this position is fed by the **Line U1**; its outlet, via signal **S2**, pilots the memory valve which enables **Line U2** and disables **Line U1**.
Line U2 pilots the main valve of cylinder **A** and its piston rod/piston completes the negative stroke.

U1 * b1 = S2 = U2 = A –

Phase 4: **C –**
Limit switch **a0** activates upon the completion of stroke **A –**, its output pilots the main valve of cylinder **C** allowing the negative stroke of its piston rod/piston.

U2 * a0 = C –

Phase 5: **B –**
Limit switch **c0** activates upon the completion of stroke **C –**, its output pilots the main valve of cylinder **B** allowing the negative stroke of its piston rod/piston.

U2 * c0 = B –

Phase 6: **C +**
Upon reaching limit switch **b0**, signal **S1**, powered by the **U2 Line**, is obtained, **S1** changes over the memory valve, reactivating **U1**.
The output of limit switch **a0**, which previously blocked the valve of the cylinder **C** is no longer active, the **U1 Line** allows the piloting of the main valve of cylinder **C** and the positive stroke of its piston rod/piston.

U2 ✲ b0 = S1 = U1 = C +

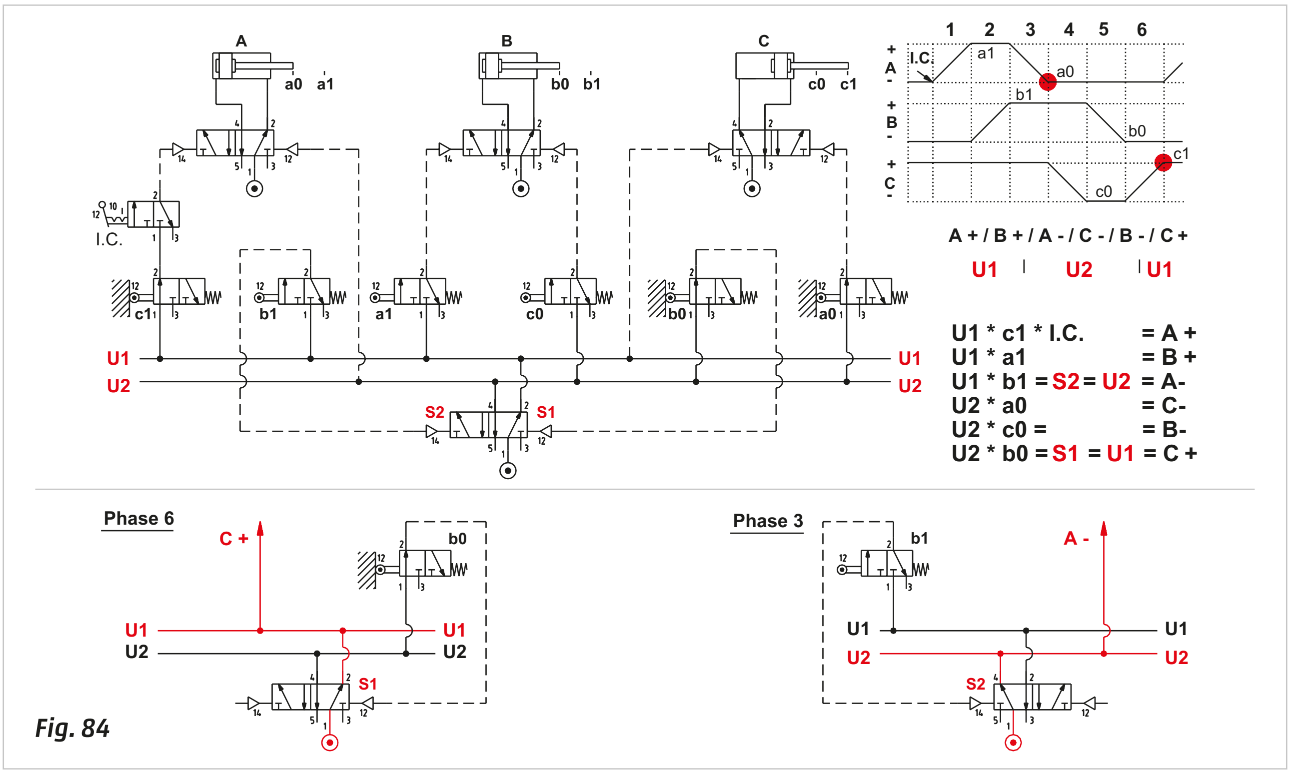


Fig. 84

Memory techniques

We analyze a new sequence and detect the presence of blocking signals.

A – / B + / B – / A +

Limit switch **a0** detects the negative stroke position of cylinder **A** and enables the positive stroke of the piston rod/piston of cylinder **B**. **a0** is also present when the piston rod/piston of cylinder **B** must complete the negative stroke, therefore **a0** is blocking.

Limit switch **b0** detects the negative end position of cylinder **B** and enables the positive stroke of the piston rod/piston of cylinder **A**. **b0** is also present when the piston rod/piston of cylinder **A** must complete the negative stroke, therefore **b0** is blocking.

We repeat the procedure described in the previous paragraph by dividing the sequence into groups.

A – / B + / B – / A +
U1 / U2

Line U1 provides power to the limit switches **a0** and **b1**.

Figure 85
Phase 1: **A –**
The last movement was that of the piston rod/piston of cylinder **A** which activated limit switch **a1**.
Its output changes over the memory valve, activating **Line U1**. The cycle start command **I.C.** is powered and its activation permits the operation of the valve of cylinder **A** and the negative stroke of its piston rod/piston.

U1 ✲ IC = A –

Figure 85

Phase 2: B +

Once the negative end position is reached, limit switch **a0** is activated, its output permits the operation of the valve of cylinder **B** and the positive stroke of its piston rod/piston.

U1 ✲ a0 = B +

Phase 3: B –

Once the positive end position is reached, limit switch **b1** is activated, by dividing the sequence into groups, the output of **b1** operating the memory valve enables **Line U2** and disables **Line U1**. By activating **Line U2**, limit switches **b0** and **a1** are powered. **Line U2** operates the valve of cylinder **B** which then executes the negative stroke of its piston rod/piston.

U1 ✲ b1 = U2 = B –

Phase 4: A +

Once the negative end position is reached, limit switch **b0** is activated, its output permits the operation of the valve of cylinder **A** and the positive stroke.

U2 ✲ b0 = A +

Once the positive end position is reached, limit switch **a1** is activated. By dividing the sequence into groups, the output of limit switch **a1** operating the memory valve enables **Line U1** and disables **Line U2**. By activating **Line U1** limit switches **b1** and **a0** and the **I.C.** command are powered.

The non-blocking limit switches can be powered directly from the network, however should **b1** or **a0** be activated accidentally, the piston rod/piston of cylinder **B** could provoke unwanted movements. The **I.C.** command can be positioned as indicated in either of the two circuits, the main valve of cylinder **B** can be either monostable or bistable.

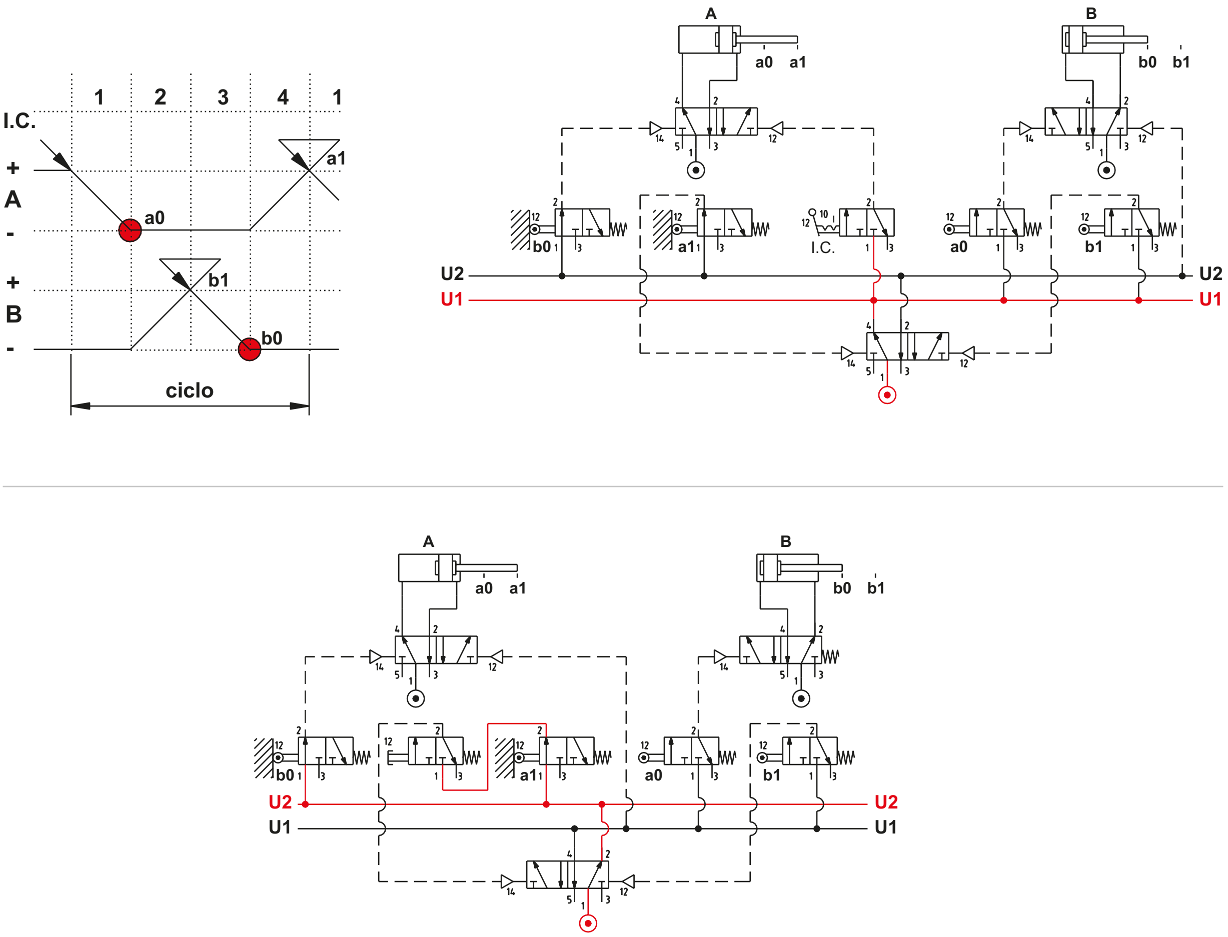


Fig. 85

Technique with memories in cascade

This is the simplest method and adaptable to any sequence.

With this technique, a relationship is established between the incoming signals from the limit switches (denoted by the letter **S** followed by a number indicating the sequence) and the output signals (denoted by the letter **U** followed by the number of the signal that generated it).

Figure 86
Pos. 1: this is the situation observed in the previous paragraph where the sequence required two power lines for the limit switches. The memory is a valve with double pneumatic command, fed by the main compressed air network. When it receives pilot signal **S1** it activates **U1**, when it receives pilot signal **S2** it activates **U2**. The presence of **U1** excludes the presence of **U2** and vice-versa.
Pos. 2: if more than two lines are necessary, proceed as follows:
The first memory valve is fed by the compressed air network, the pilot signal **S1** activates **U1** which, in addition to feeding the limit switch, allocates the position of the subsequent memory valve.
Pos. 3: with the arrival of pilot signal **S2**, connected to the memory valve fed by the compressed air network, it changes over, interrupting the output which enabled **Line U1**, it also activates the output that feeds the previously positioned valve. The new output is line **U2**.
Pos. 4: in the presence of the pilot signal **S3**, **Line U3** is activated, thus interrupting **U2**.

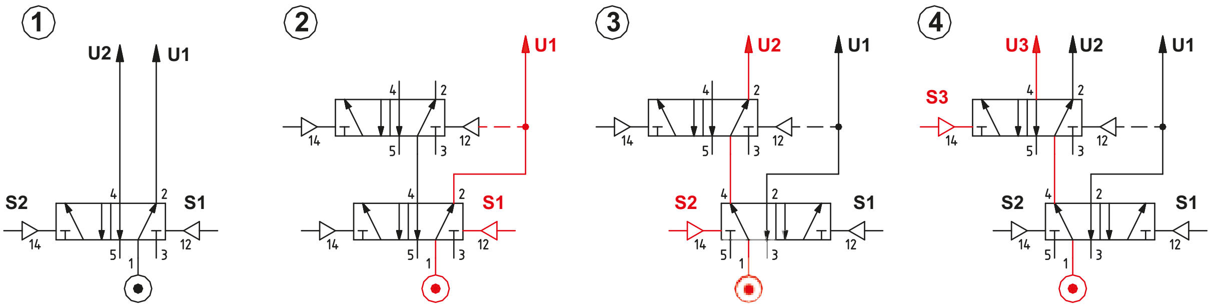


Fig. 86

Two connected memory valves can provide three power Lines and only one of these three can be active, should additional Lines be needed more memory valves are added.

Given a sequence and having identified the presence of blocking signals, the sequence is divided into groups, so that the letters which identify the cylinders do not appear more than once in the same group, the number of memory valves needed is equal to the number of groups minus one.

Figure 87
Pos. 5: with respect to Pos.4. a memory valve has been added to obtain **U4**. When signal **S4** is present, **U4** is activated, interrupting **U3**.
Pos. 6: with the removal of signal **S4**, and in the presence of signal **S1** the cascade is reset, reactivating **U1**. When drawing a pneumatic circuit which includes this technique, an external reset system of the cascade should be included to be used during the **Reset** phase after an emergency stop.

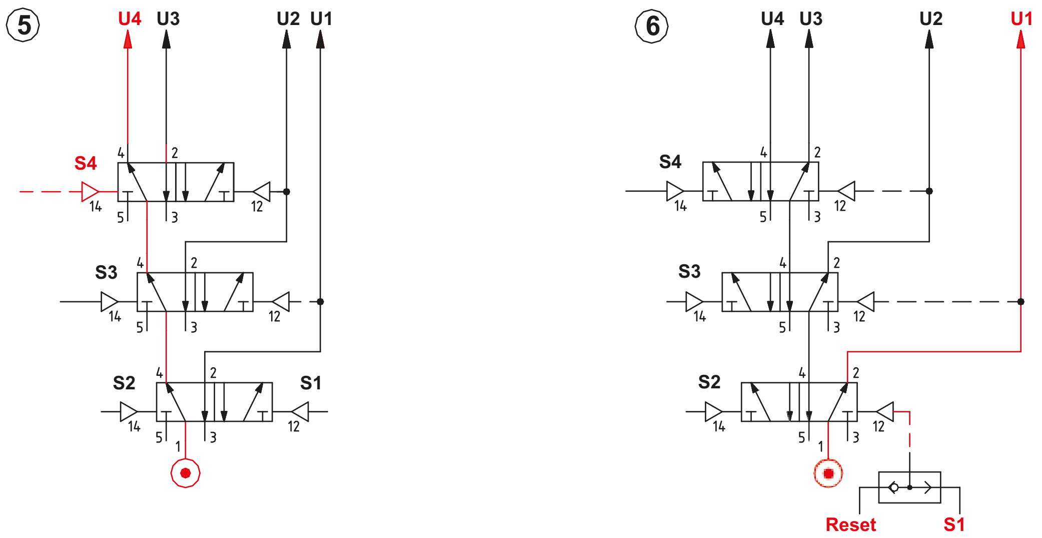


Fig. 87

Memories in cascade

We draw the pneumatic circuit of a hypothetical sequence, analyzing the movements of the cylinders Phase by Phase. A workstation is required in order to perform the following operations:

Positioning of the component	cylinder **A**
Clamping the piece	cylinder **B**
Drilling operation	cylinder **C**
Boring operation	cylinder **D**

The sequence to be realised is:

A +	/	A –	/	B +	/	C +	/	C –	/	D +	/	D –	/	B –
1		2		3		4		5		6		7		8

Required conditions:

The Start command is achieved by pressing the **I.C.** button, in this example the Emergency stop function is not implemented. If the workstation is inactive, the limit switches, even if activated, are also inactive.

Selection of main valves:

Analyzing the sequence, we observe that cylinders **C** and **D** reverse their direction through their respective positive limit switches **c1** and **d1**. For these cylinders, the main valves can be **monostable**. For cylinder **A** this selection is not possible as the operator acts with a short impulse signal for the Start, the valve in this case is **bistable**.
Cylinder **B** requires a **bistable** valve, as it remains at the respective end positions for more than one Phase.

Search for blocking signals, division into groups and calculation of the necessary number of memory valves:

We subdivide the sequence into groups ensuring the letters representing the cylinders do not appear more than once in the same group, we identify the required memory valves.

A +	/	A – / B +/ C +	/	C – / D +	/	D – / B –
U1	/	U2	/	U3	/	U1

U1 feeds the limit switches in positions **a1**; **d0**; **b0**

U2 feeds the limit switches in positions **a0**; **b1**; **c1**

U3 feeds the limit switches in positions **c0**; **d1**

The number of memory valves to use in order to realize a cascade are two (number of groups minus 1).

We represent the cylinders and their main valves, the two memory valves connected in cascade, the limit switch **b0**, which was the last to be operated, and the **I.C.** valve.

Figure 88

Phase 1: adhering to the division of the groups, **U1** is active and feeds limit switch **b0**. The start of the cycle requires the presence of the **I.C.** command and **b0**, the output signals from these valves, via the **AND** function, operate the main valve of cylinder **A**, which, by changing over, allows the piston rod/piston to complete positive stroke **A +**.
The **Line U1** prepares the subsequent memory valve, in addition to powering limit switch **b0**.

U1 ∗ I.C. ∗ b0 = A +

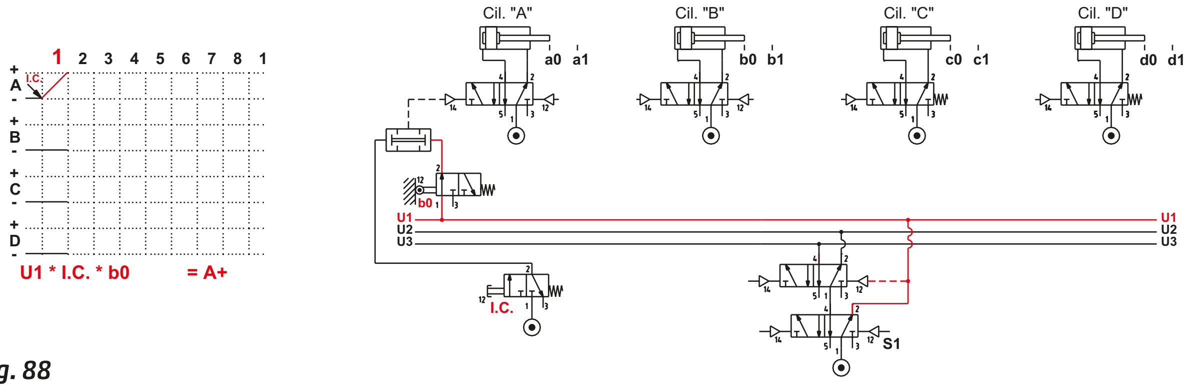


Fig. 88

Figure 89

Phase 2: once the piston rod/piston of cylinder **A** has reached the end position, it activates limit switch **a1**, which is also fed by the **U1 Line**, as it belongs to the same group, signal **S2** is generated, operating the memory valve and changing its state. By changing over, the memory valve interrupts **Line U1** and activates **U2**. **Line U2** is directly connected to pilot port 12 of the main valve of cylinder **A** to execute the negative stroke **A –**.
Activating the **I.C.** button does not result in any movement, as **Line U1** is no longer active.

U1 ✻ a1 = S2 = U2 = A –

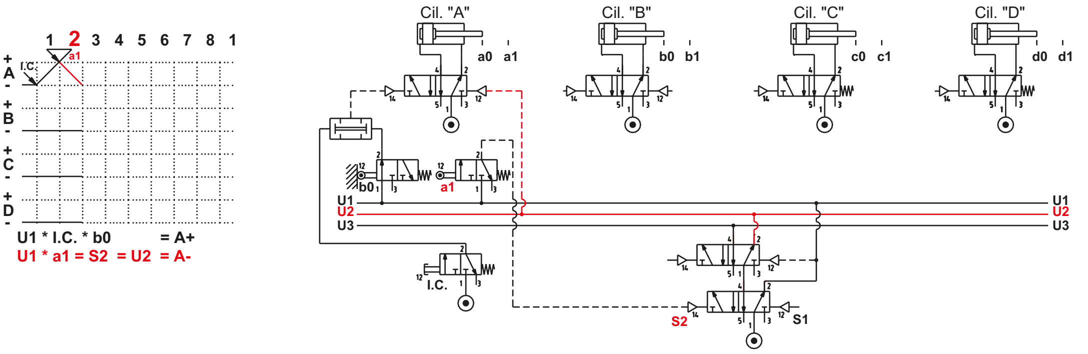


Fig. 89

Figure 90

Phase 3: the piston rod/piston of cylinder **A** reaches and activates limit switch **a0**, whose output operates the main valve of cylinder **B** in order to execute the stroke **B +**.

U2 ✻ a0 ✻ = B +

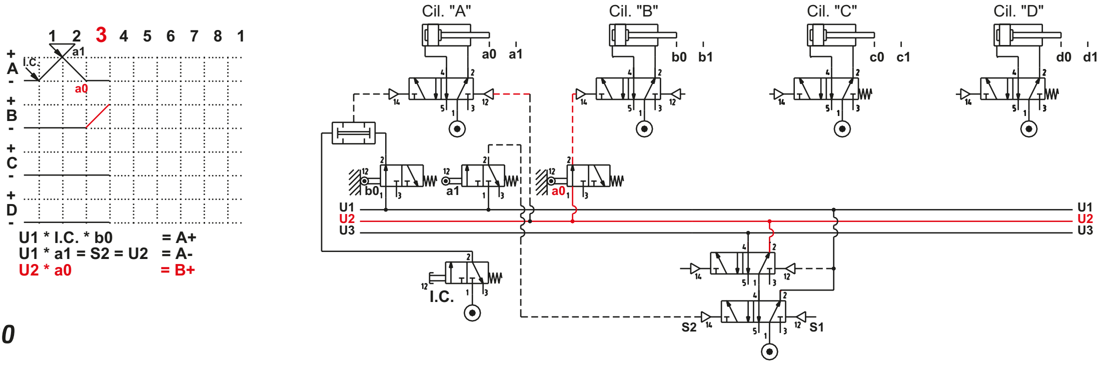


Fig. 90

Figure 91

Phase 4: the piston rod/piston of cylinder **B** reached and activates limit switch **b1**, whose output operates the valve of cylinder **C** in order to execute the stroke **C +**.

U2 ✻ b1 ✻ = C +

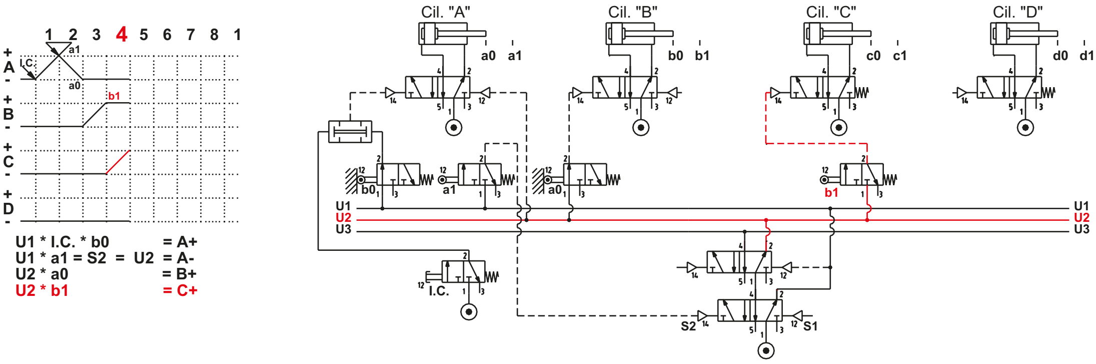


Fig. 91

Figure 92

Phase 5: in this Phase, once limit switch **c1** is reached, we need to change the Line from **U2** to **U3**. The output signal coming from the limit switch **c1** corresponds to the pilot signal **S3** of the memory valve, which activates **Line U3** by changing over.

With the removal of **Line U2**, the monostable valve of cylinder **C** assumes the position defined by the spring, the piston rod/piston changes direction and returns to its negative end position.

U2 * c1 = S3 = U3 = C –

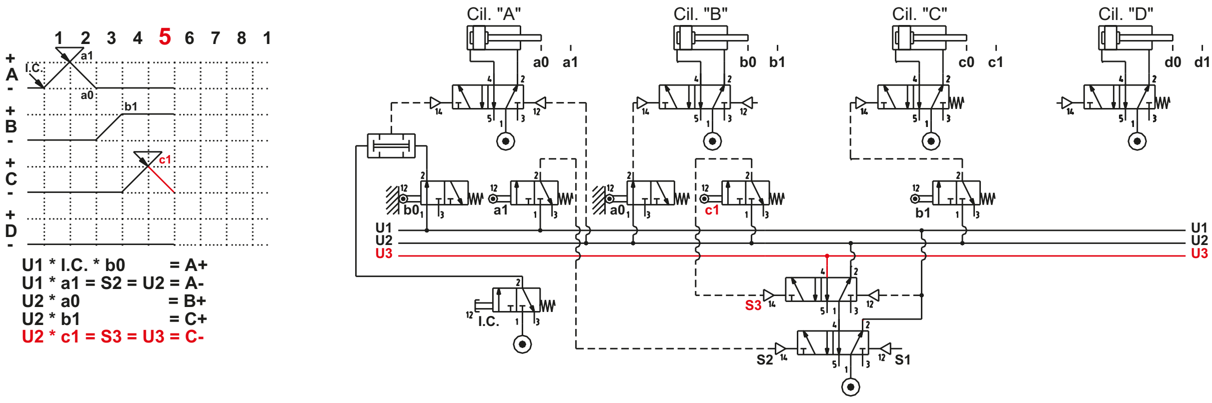


Fig. 92

Figure 93

Phase 6: **Line U3** feeds limit switch **c0** which, activated by the return of cylinder **C** operates the main valve of the cylinder **D**, stroke **D +** is obtained.

U3 * c0 = D +

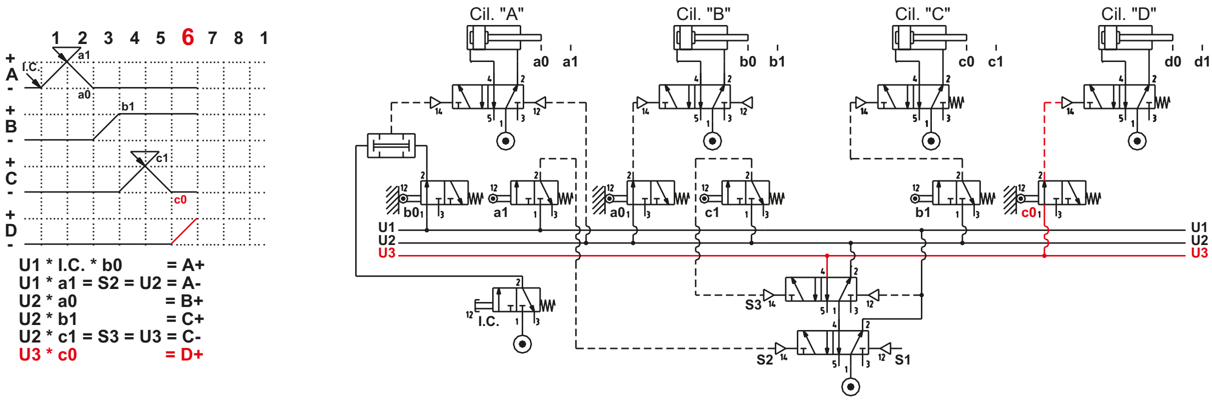


Fig. 93

Figure 94

Phase 7: the piston rod/piston of cylinder **D** completes the positive stroke, it reaches and activates limit switch **d1**, whose output **S1** operates the first memory valve, resetting the cascade, interrupting **Line U3** and reactivating **Line U1**. The interruption of **Line U3** cancels the operation on the monostable valve of cylinder **D**, which, by repositioning itself, allows the piston rod/piston to complete its negative stroke.

U3 * d1 = S1 = U1 = D –

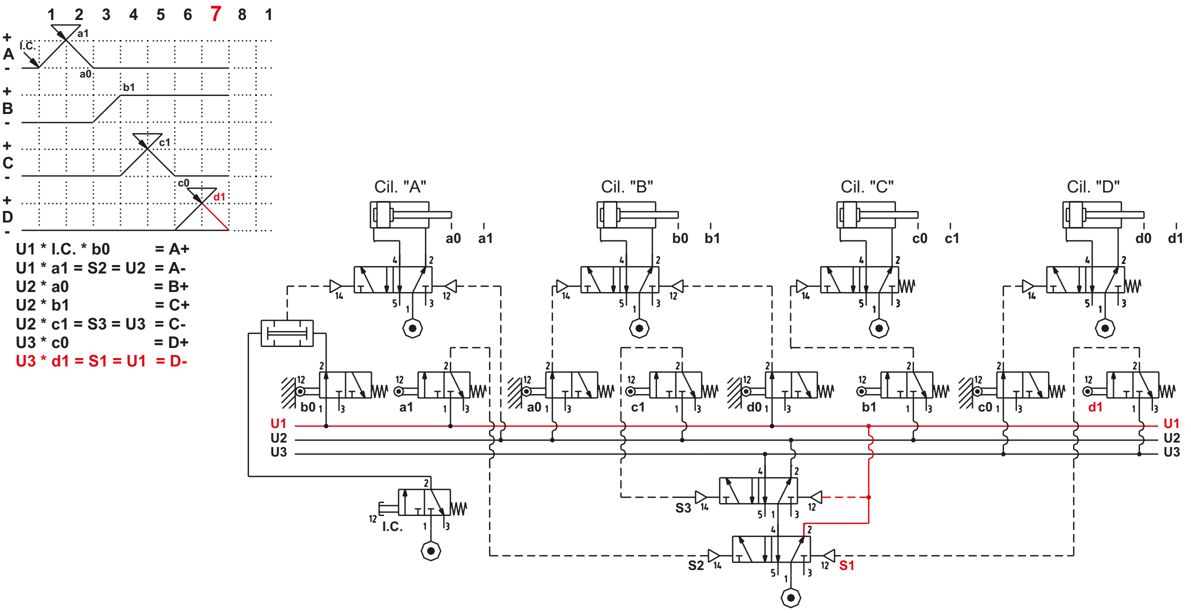


Fig. 94

Figure 95

Phase 8: the piston rod/piston of cylinder **D** completes the negative stroke, reaches and activates limit switch **d0**, whose output operates the valve of cylinder **B**, permitting the piston rod/piston to complete the negative stroke.

U1 ✻ d0 = B -

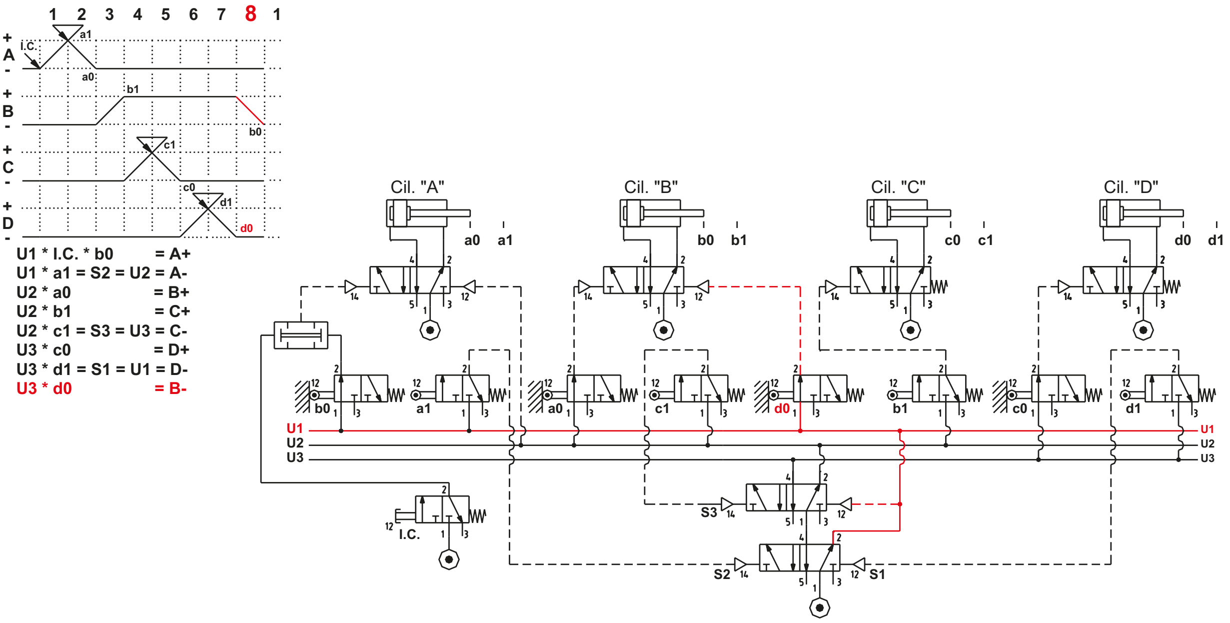


Fig. 95

The cycle has completed and we return to the initial state with **U1** active, the position of cylinder **B** is confirmed, and the sequence is ready for a new cycle.

Unwanted movements are a possibility in the event of unintended activation of certain limit switches if powered by the main network. Besides blocking signals, also the possibilies are avoided however by applying the technique with memories in cascade. The use of monostable valves must always be evaluated, particularly for the control of actuators with gripping or locking functions.

Repetitive signals

We analyze the following example with repeated movement of the same cylinders in different Phases.
As an example, we observe the following sequence:

A + / B + / B – / A – / B + / B –

The piston rod/piston of cylinder **B** oscillates repeatedly. The limit switches **a1** and **a0** both operate the main valve of cylinder **B** in order to execute the positive stroke. The limit switch **b0** in **Phase 3** operates the main valve of the cylinder **A** to execute the negative stroke **A –**, while in **Phase 6** the limit switch **b0** operates the main valve to enable the positive stroke **A +**. The movement of cylinder **B +** is a function of the actuation of limit switches **a1** and **a0**, the movements **A +** and **A –** are a function of the limit switch **b0**.

We divide the sequence into groups and determine how many lines and memories are needed.

A + / B +	/	B – / A –	/	B +	/	B –
U1	/	U2	/	U3	/	U4

4 lines and 3 memories are required.

Figure 96
Phase 1: **Line U1** is active, the limit switch **b0** is activated and fed from the compressed air network.
The output signal from the limit switch **b0** fulfils two functions:

- when **b0 AND Line U1** is TRUE, then the **I.C.** valve has air supply to Start the sequence **A +**
- when **b0 AND Line U2** is TRUE, then the movement **A –** is permitted.

U1 ✻ I.C. ✻ b0 = A +

Phase 2: the piston rod/piston of cylinder **A** executes its positive stroke, then reaches and actuates the limit switch **a1** whose output through the **OR** function, operates the main valve of cylinder **B**, the piston rod/piston of cylinder **B** executes the positive stroke.

U1 ✻ a1 = B +

Phase 3: the piston rod/piston of cylinder **B** actuates the limit switch **b1** whose output signal generates the pilot signal **S2**, which operates memory valve and charges it over, interrupting **U1** and activating **U2**, the limit switch **a1** is no longer fed with compressed air, this means that the main valve of cylinder **B** (being monostable) returns to its rest position, the piston rod/piston starts its movement in the negative direction **B –**.

b1 = S2 = U2 = B –

Phase 4: the limit switch **b0** fulfils the second of the afore-mentioned functions; when **b0 AND U2** is TRUE, then the movement of the piston rod/piston of cylinder **A** towards the negative position **A –** is enabled.

U2 ✻ b0 = A –

Phase 5: the limit switch **a0** is fed by **U2** and with its actuation, the signal **S3** is generated, which operates the memory valve, interrupting **U2** and activating **U3**. The output of **U3**, via the **OR** function, operates the pilot port of the monostable valve of cylinder **B**, which by changing over initiates the movement of the piston rod/piston of cylinder **B** in the positive direction **B +**.

U2 ✻ a0 = S3 = U3 = B +

Phase 6: when the limit switch **b1** is reached, the following conditions apply; when **b1 AND Line U3** is TRUE, then the signal **S4** is generated, which operates the memory valve, interrupting **Line U3** and activating **Line U4**. Activating **Line U4**, the limit switch **a1** is no longer fed with compressed air which means the main valve of cylinder **B** (being monostable) returns to its rest position, the piston rod/piston starts its movement in the negative direction **B –**. When the signal from limit switch **b0 AND Line U4** is TRUE, the signal **S1** is generated, resetting the memory cascade.

U3 ✻ b1 = S4 = U4 = B –

Finally, we report the initial condition at completion of stroke **B**:

U4 * b0 = S1 = U1

The sequence has terminated and awaits a new Start command from the **I.C.** valve**.**

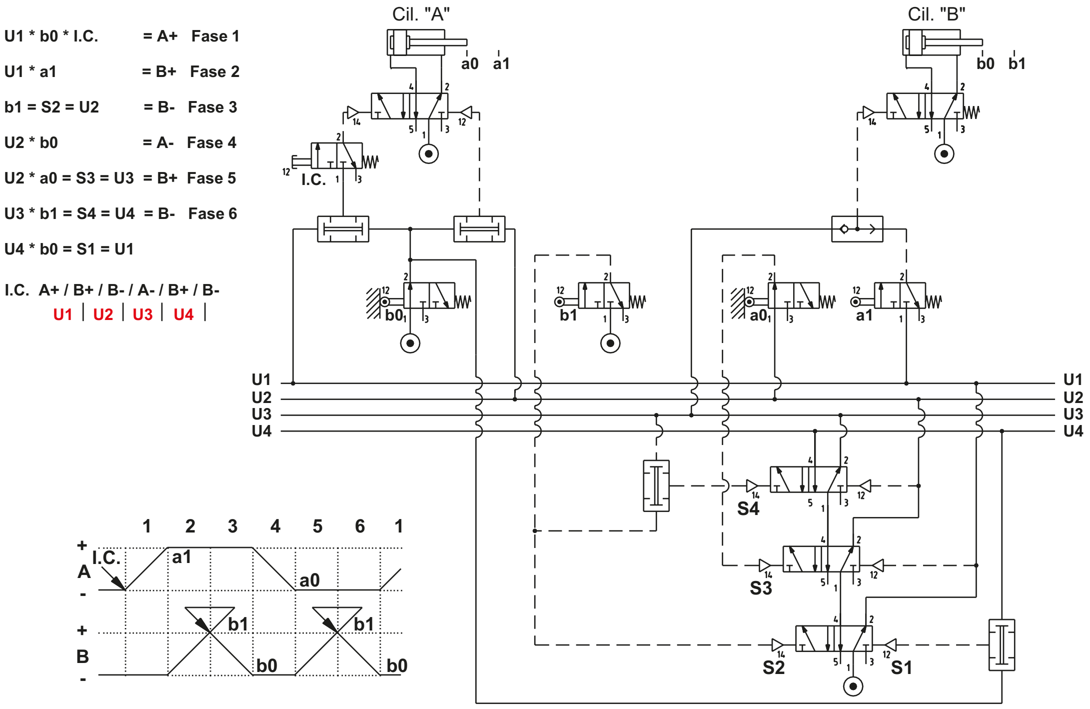


Fig. 96

The sequencer

The preliminary analysis required will depend on the method adopted for the realization of the circuit, as regards to the feeding of the air supply to the limit switches that generate blocking signals.
In certain cases, the circuit can be simplified by repeatedly using at least two pneumatic functions, a 3/2-way memory valve and a logic AND function. These elements can be connected and integrated in a single device – **sequencer**.

With the sequencer device, the blocking signals or their duration are no longer determinant.

Figure 97
Pos. 1: a **3/2-way** memory valve is drawn in the **open** position and fed by the main compressed air network, its output is defined as **U1**. This output allows the advancement of the cycle or to feed the Start button with compressed air.
Pos. 2: the output **U1** is connected to an **AND** function in parallel. The output of this function is only activated in the presence of signal **S1** from the first limit switch actuated after the start of the cycle.
Pos. 3: the signal **S1** is now present, the output of the **AND** function is active and operates the memory valve of the successive sequencer, which generates output **U2** by opening. This output, in addition to being used as a pilot signal for valves in the circuit, closes the **3/2-way** memory valve which generated **U1**. Closing the memory valve, output **U1** is exhausted and consequently also the pilot signal **12** of the memory valve that generated output **U2**.

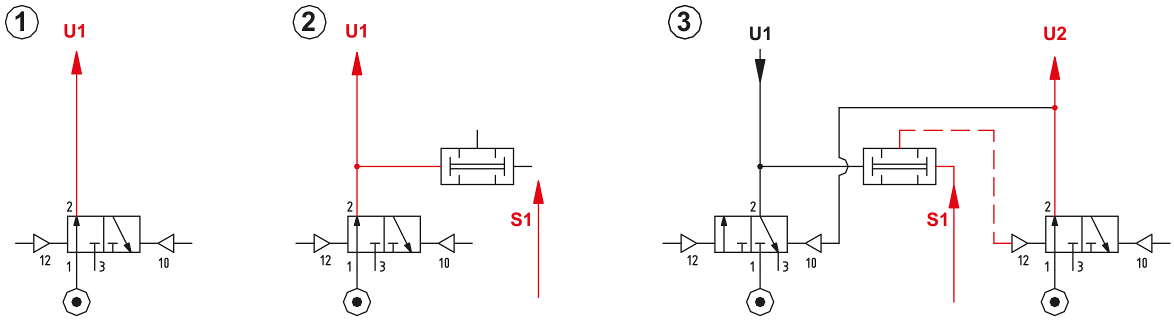


Fig. 97

Figure 98
Pos. 4: in addition to the functions described above, output **U2** feeds the input of a new **AND** function.
Even if signal **S1** is present, there is no output from the **AND** function because there is no input **U1**.
Pos. 5: the main valve operated by output **U2** dictates the movements of some of the actuators, this movement must be detected by a limit switch e.g., which will generate an output signal.
This signal becomes **S2** which is the input of the new **AND** function, activating it operates the memory valve of the subsequent sequencer and output **U3** is generated. As in Pos 3, output **U3**, besides being used as a pilot signal to the valves in the circuit, has the function of closing the **3/2-way** memory valve that generated **U2**. As the memory valve closes, the output of **U2** is exhausted and consequently also the pilot signal **12** of the memory valve which generated output **U3**.

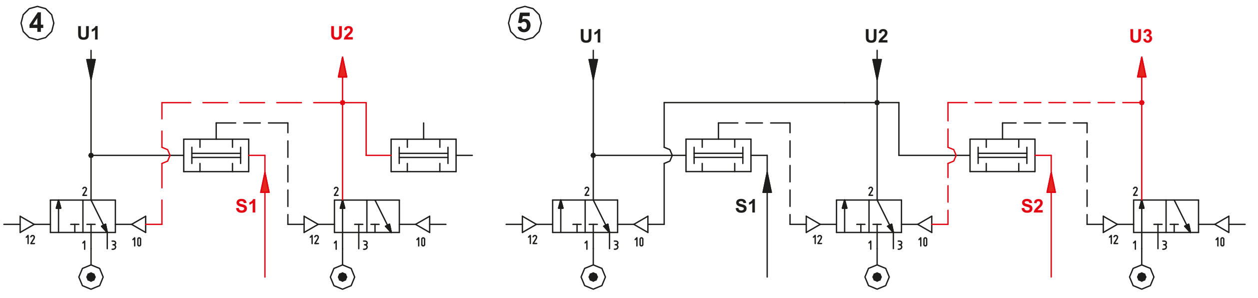


Fig. 98

After illustrating the operating principles, we analyze how to use them to develop a sequence. The sequence to be realized is:

A + / B + / B – / C + / C – / A –

Conditions: initiate with Start Cycle button **I.C.**

Selection of main valves:
Cylinder **A**: the **bistable** function is preferred, as the cylinder remains in the positive end position for almost the entire sequence.
Cylinders **B** and **C**: in this case a **monostable** function is preferred.

This sequence incorporates blocking signals also:
a1 is present during both the **B +** stroke and the **B –** stroke
b0 is present during both the **C +** stroke and the **C –** stroke
c0 is present during both the **A –** stroke and the **A +** stroke
Using the sequencer all these signals can be ignored.

Typically, this circuit represents the system at rest, (start position). Both the limit switches and the main valves that operate the cylinders are powered by the main compressed air network.

Figure 99
Pos. 1: the memory valve in the **first** sequencer (**MS1**) is open, its output is defined as **U1**, it feeds the **I.C.** button and the logic **AND** element of the second sequencer (**MS2**).
The **Start** command is provided by the activation of the **I.C.**, it operates the main valve of cylinder **A** and allows this piston rod/piston to execute the positive stroke **A +**.
Pos. 2: once the **A +** stroke has reached its positive end position, limit switch **a1** is actuated, and its output together with **U1**, is connected to the two inlets of the logic **AND** element (**MS2**). The output of the **AND** element operates the memory valve, which, by opening the passage, generates **U2**.
With the activation of the **U2 Line**, we have:
- the operation of the main valve of cylinder **B** in order to obtain **B +**
- the reset of the memory valve of the sequencer **MS1** and the consequent interruption of **U1**
- preparation of the **AND** function of sequencer **MS3**.

The **U2 Line** remains active until the activation of limit switch **b1**, which detects the arrival at position **B +**.

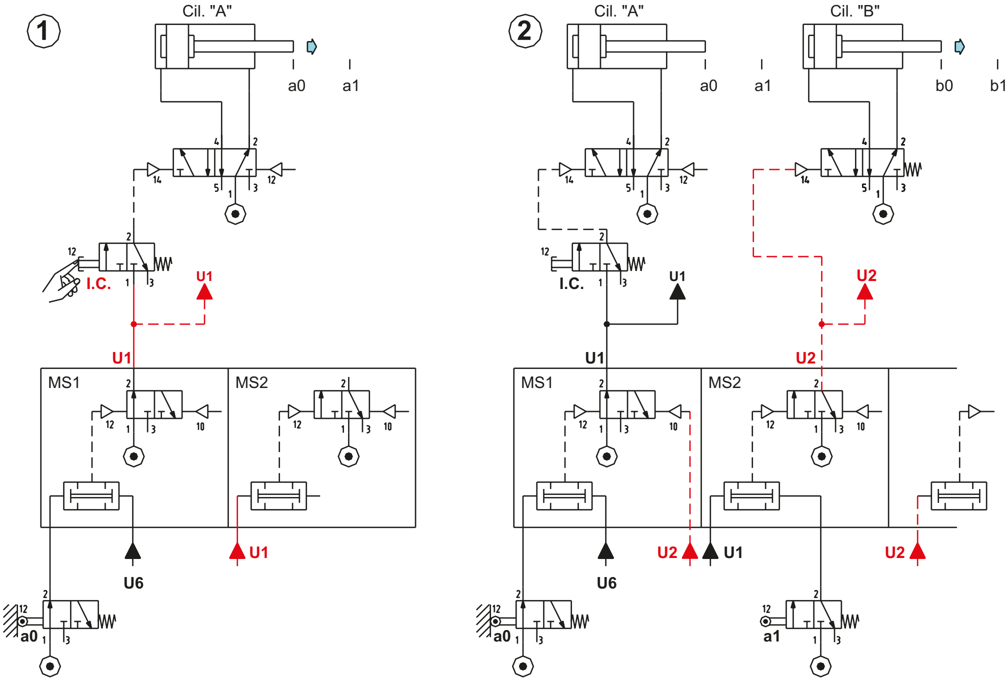


Fig. 99

a0 * U6 = U1 * I.C. = A +

a1 *U1 = U2 = B +

Figure 100

Pos. 3: once the piston rod/piston of cylinder **B** has completed its positive stroke, it actuates limit switch **b1**, which emits an output signal. This signal, and the confirmation of the presence of **Line U2** are connected to the two inlets of the **AND** element of sequencer **MS3**. The output of the **AND** operates the memory valve which by opening the passage, generates **Line U3**.

With the activation of the **Line U3** we have:

- the reset of the memory valve of sequencer **MS2** and consequently the interruption of **Line U2**, the changing over of the main valve of cylinder **B** (monostable) and the return of the piston rod/piston of cylinder **B**
- preparation of the **AND** function of sequencer **MS4**.

Pos. 4: once the piston rod/piston of cylinder **B** has completed its negative stroke, it actuates limit switch **b1**, which emits an output signal. This signal, together with the confirmation of the presence of line **U3**, is connected to the two inlets of the **AND** element of sequencer **MS4**. The output of the **AND** operates the memory valve which generates **Line U4** by opening the passage.

With the activation of the **Line U4** we have:

- the operation of the main valve of cylinder **C** in order to obtain the positive stroke **C +**
- the reset of the memory valve of sequencer **MS3** and the consequent interruption of **U3**
- preparation of the **AND** function of sequencer **MS5**.

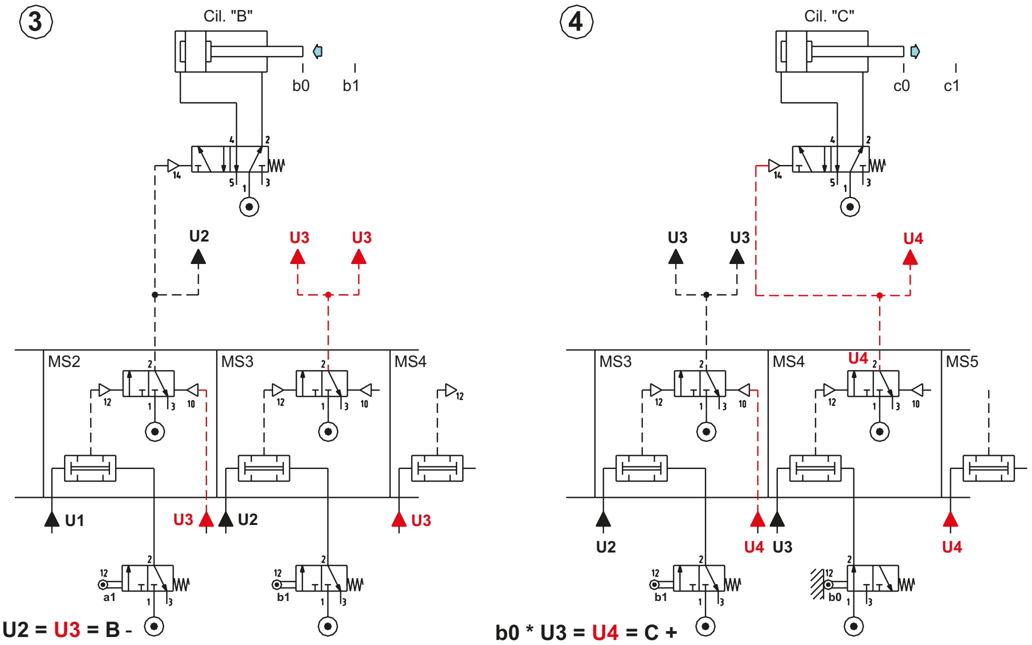


Fig. 100

b1 * U2 = U3 = B -

b0 * U3 = U4 = C +

Figure 101

Pos. 5: once the piston rod/piston of cylinder **C** has completed its positive stroke, it actuates limit switch **c1**, which emits an output signal. This signal, together with the confirmation of the presence of **U4** is connected to the two inlets of the **AND** element of sequencer **MS5**. The output of the **AND** operates the memory valve which generates **Line U5** by opening the passage.

With the activation of the **Line U5** we have:

- The reset of the memory valve of sequencer **MS4** and consequently the interruption of **U4**, the changing over of the main valve of cylinder **C** (monostable) and the return of the piston rod/piston of cylinder **C** at the negative end position.
- Preparation of the **AND** function of sequencer **MS6.**

Pos. 6: once the piston rod/piston of cylinder **C** has completed its negative stroke, it actuates limit switch **c0**, which emits an output signal. This signal, together with the confirmation of the presence of **Line U5**, is connected to the two inlets of the **AND** element of sequencer **MS6**. The output of the **AND** operates the memory valve which generates **Line U6** by opening the passage.

With the activation of the **Line U6** we have:

- the operation of the main valve of cylinder **A** in order to obtain **A –**
- the reset of the memory valve of sequencer **MS5** and the consequent interruption of **U5**
- preparation of the **AND** function of sequencer **MS1**.

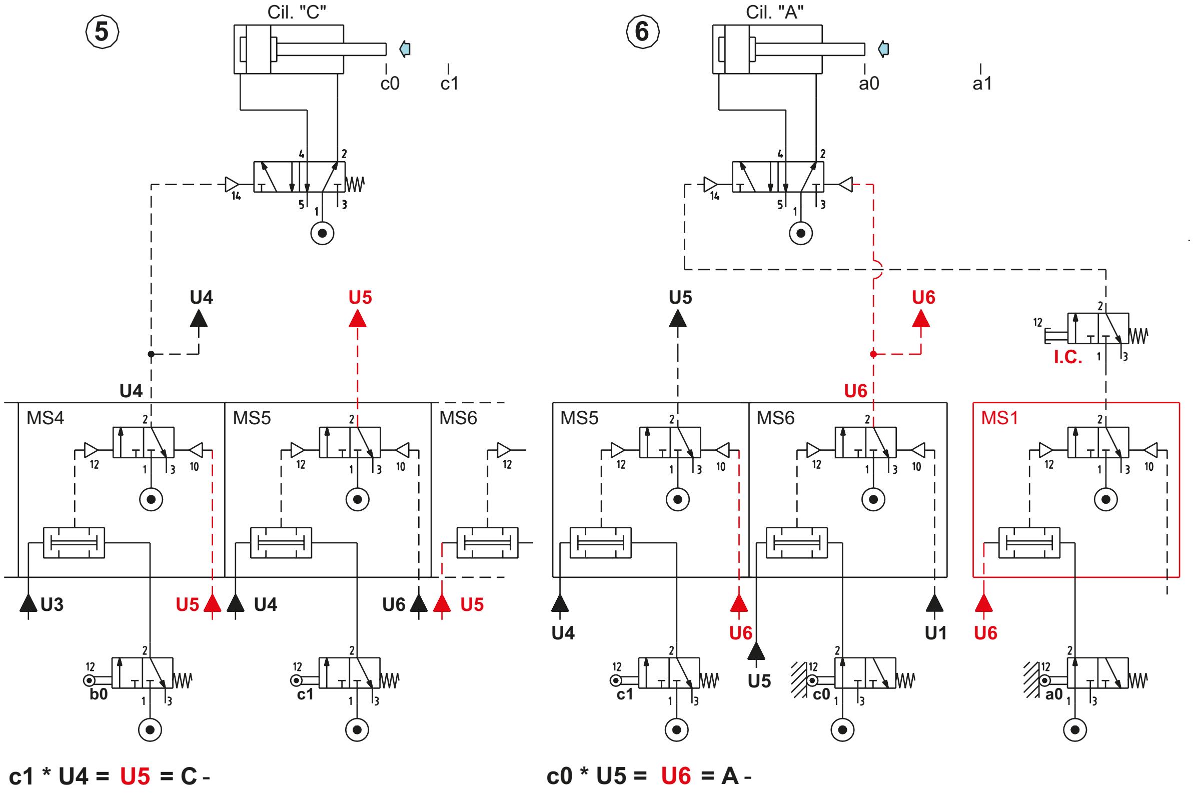


Fig. 101

Figure 102

The piston rod/piston of cylinder **A** actuates the limit switch **a0** when it reaches its terminal position. The output of **a0** and **U6** are connected to the **AND** function of sequencer **MS1** which generates the output. This output signal operates the memory valve which by changing over, generates **Line U1**.

With the activation of the **U1 Line**, we have:

- compressed air supply for the **I.C.** button for the beginning of a new cycle
- the reset of the memory valve of sequencer **MS6** and subsequent interruption of **Line U6**.

The cycle has been completed, the sequencer is ready for a new cycle, the blocking signals do not interfere and the development/drawing of the circuit is simplified.

The number of sequencers to be used corresponds to the number of phases in the sequence.

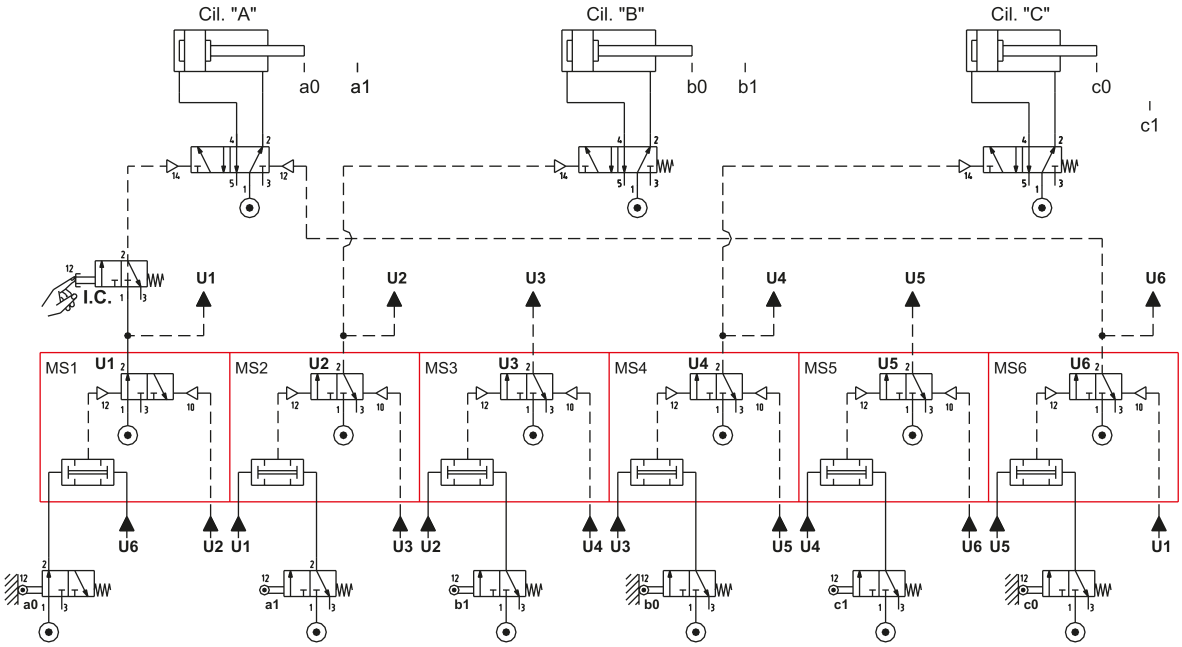


Fig. 102

Figure 103
With this example the emergency stop and cycle reset commands are introduced.

Emergency: a bistable 5/2-way valve has been used, in the shown position it feeds all the limit switches; when actuated it doesn't allow the sequencer to continue the cycle, as it interrupts the compressed air supply, **stopping the cycle in its current Phase.**
Resetting the **EM** command, the sequencer **resumes from the Phase in which it had stopped**.

Reset: this command is active only during the **EM** phase. If actuated, the memory valves of all the sequencers (**MS**) will reset, putting them in the closed position, the bistable valve which controls cylinder **A** repositions itself. Another function is to prepare the 3/2-way memory valve to feed the **I.C.** command via the **OR** function and the **U6** command in the **open** position**.**

As indicated in the previous chapters, the **EM** and **Reset** functions must be properly analyzed in order to prevent damage to equipment. The example described above is for educational purposes only.

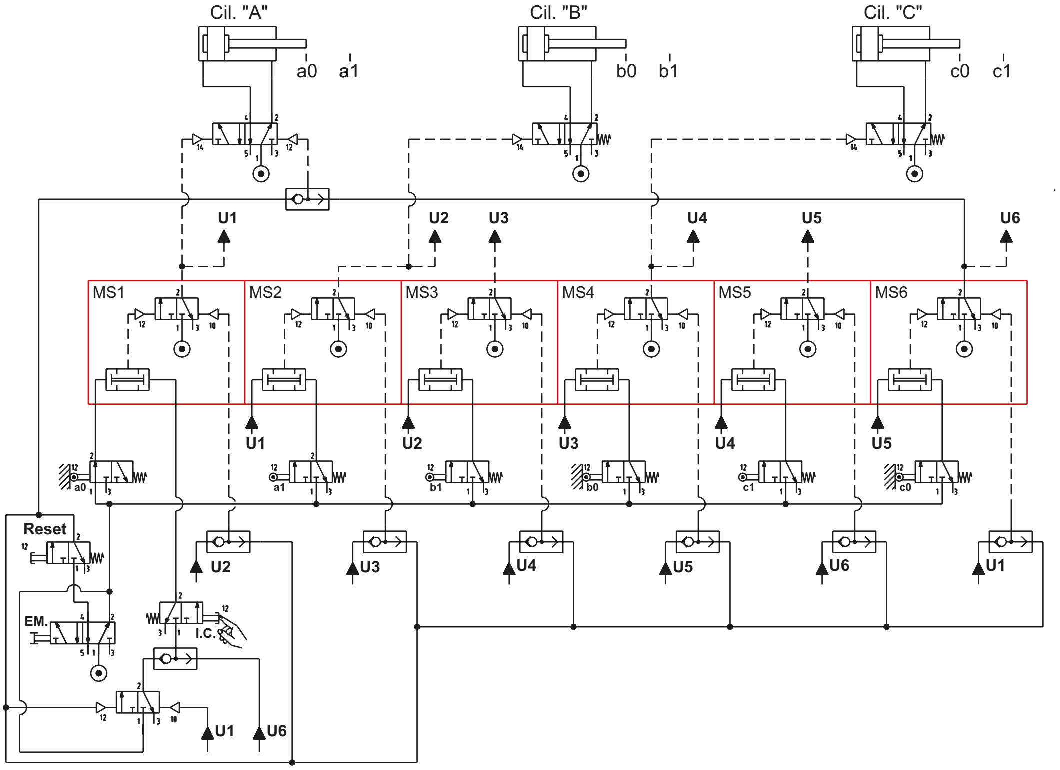


Fig. 103

Two-hand control unit

In the sequences described in previous paragraphs, the safety elements that require use of both hands in order to initiate the start cycle command, have not been incorporated.

The general rules delineate the safety requirements in the workplace, both within the operating range of the equipment and beyond. The equipment manufacturer will determine the most suitable conditions for EM operation, such as the interruption of electrical and pneumatic power, positioning of moving components. Regarding the cycle start command, the manufacturer of the system must decide whether to implement a traditional start system or **Two-Hand** device, based on the position of the operator and the machine or its mechanical components.

The Two-Hand control unit permits an output signal only in the presence of two simultaneous inputs (given by the simultaneous pressing of both buttons by the operator). The pneumatic circuit responsible, generally represented in the box with a dashed green line, is integrated into a single block which is connected to the outputs of the buttons. in this case manual valves **P1** and **P2**.
A certain distance is required between the two valves so as to prevent them from being operated with a single hand. When they are activated the output signal reaches both the OR function as well as the AND function.
The output signal of the OR function, via a unidirectional flow regulator with a fixed calibration, is used to regulate the filling time of the capacity connected in series, so as to delay the operation of the bistable 3/2-way valve.
This delay, even if small, permits the signal of the AND function to reach the 3/2-way valve faster, thereby opening it at the same time as the buttons are activated. If one of the two buttons were to be activated with a slight delay, the output signal of the OR would reach the 3/2-way valve maintaining it in the closed position.
At the release of one of two buttons the output of the AND function is interrupted and the 3/2-way valve closes when reached by the signal from the OR.

Consider the movement of two cylinders with the sequence:

A + / B + / A – / B –

Figure 104
Required conditions for the **I.C.** command:

- simultaneous signals from the two buttons **P1** and **P2**.
- If one of the two buttons is always active (blocked by external means) the start of the cycle is not possible.
- If one of the two buttons is released during stroke **A +**, the cylinder must reverse its stroke returning to its negative end position.
- The operator can only release the buttons once limit switch **a1** is reached.
- The buttons can only be operated when cylinder **B** is in negative end position.

Choice of control valves:

- prerequisite for **Phase 1**; cylinder **A** must be connected to a 5/2-way monostable valve.
- For cylinder **B**, it is preferable to use a bistable valve due to the presence of intermediate phases between positive and negative strokes.

The limit switch **b0** feeds the two buttons **P1** and **P2**, their outlets are connected to the two inlets of the Two-hand control unit, whose output is connected to **I.C.** in the flow diagram. The **I.C.** signal, in addition to operating the pilot port of the monostable 5/2-way valve that enables the movement **A +**, also feeds limit switch **a1**, which is not activated at present.
When the piston rod/piston of cylinder **A** reaches limit switch **a1**, there is an output signal which operates: the main valve of cylinder **B** for movement **B +** and the opening of the 3/2-way memory valve, whose outlet substitutes that of the two-hand unit. The buttons can now be released. The piston rod/piston of cylinder **B**, when terminating the positive stroke, activates limit switch **b1** whose output repositions the 3/2-way valve. This valve, by closing, removes the pilot signal of the valve of cylinder **A** and the power supply of limit switch **a1**. In the absence of this signal, the monostable function of the valve initiates the return stroke **A –** and the subsequent activation of **a0**. The output signal from limit switch **a0** operates the valve of cylinder **B** which allows the stroke **B –**, the cycle terminates.

This illustrated exercise is purely demonstrative and does not adhere to any current regulations regarding safety etc.

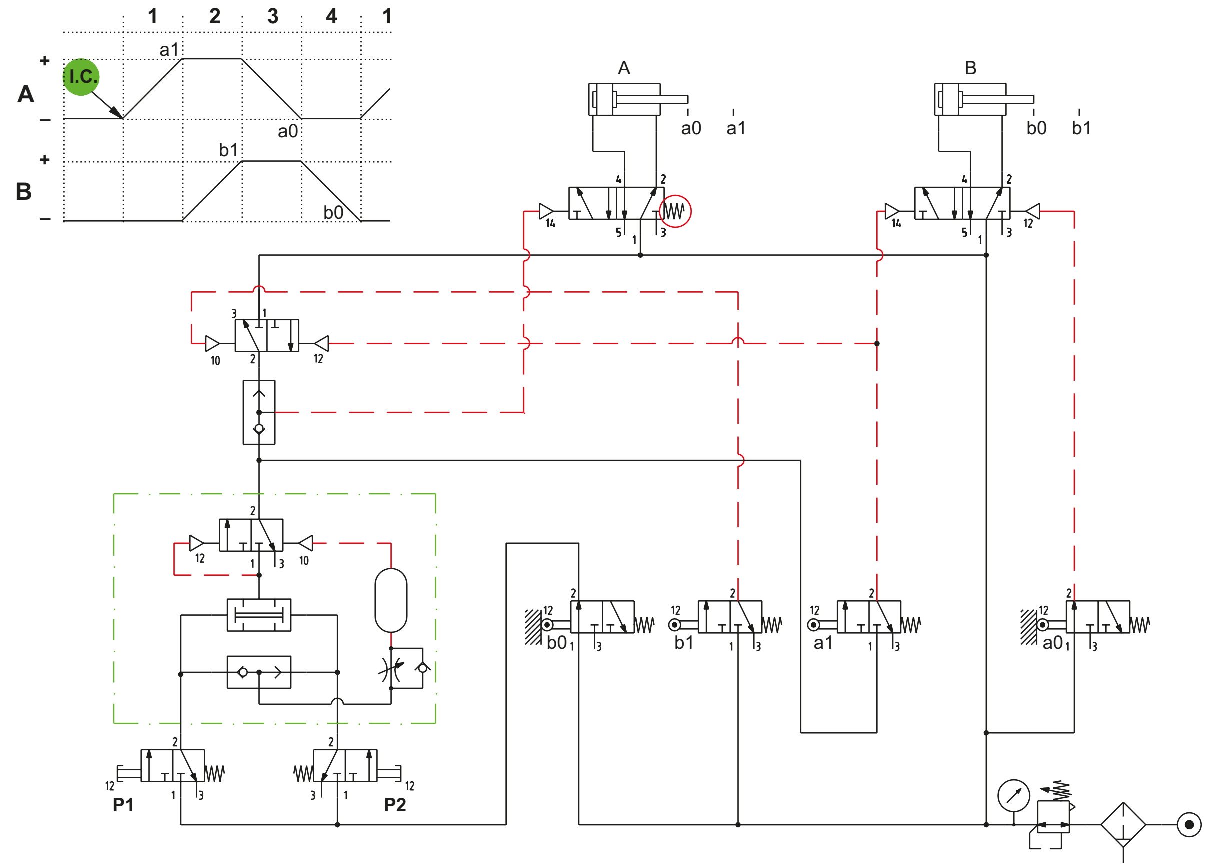

1
2
3
4
1
A
+
−
I.C.
a1
a0
B
+
−
b1
b0
A
a0
a1
B
b0
b1
4
2
14
5
1
3
12
3
1
10
2
12
2
12
1
3
10
2
12
b0
1
3
12
b1
1
3
12
a1
1
3
12
a0
1
3
2
12
P1
1
3
2
3
1
P2
12

Fig. 104

CHAPTER 6

ELECTRO-PNEUMATIC CIRCUITS

Electrical symbols

In the pneumatic and electrical lexicon, we use definitions Normally Open and Normally Closed.

These definitions, respective of their context will vary in meaning:

- **pneumatic**: as observed in previous paragraphs, a valve is open when air or some other fluid circulates, and closed when there is no passage (flow).
- **electrical**: we use contacts instead of valves and the contacts consist of two metal parts, one of which is mobile. When the contact is defined as "normally open", the electrical current is unable to pass as the two conductors are not connected. When the contact is defined as "normally closed", the current passes through, as the two conductors are now connected.

The contacts may have different methods of activation: manual, mechanical or electrical, and are found in many electrical components such as switches, push buttons, relays, contactors, timers, etc.
These elements are generally connected (electrically) via terminals or sockets.

In pneumatic circuit diagrams, the distribution network of the compressed air is indicated by a continuous line while the operating signals are represented by a dashed line.
In electric circuit diagrams the power line is represented by two continuous thick lines, the logic lines derive from the power lines, they are thinner and indicate various functions such as the coils of the conductors or relays, or their contacts or loads etc.

An electric circuit diagram is read from top to bottom and from left to right. It is advisable to indicate each logic line with a number and identify the contact with the letter of the relay to which it belongs.

Figure 1
Pos. 1:
A: power line
B: connection point
C: lines intersecting without connection
Pos. 2:
A: push button command with an **NO** contact
B: push button command with an **NC** contact
Pos. 3:
A: selector command with **NO** contact
B: selector command with **NC** contact
Pos. 4:
A: emergency push button command with an **NO** contact
B: emergency push button command with an **NC** contact
Pos. 5: exchanging/switching contact
Pos. 6:
A: micro switch with **NO** contact for end position detection
B: micro switch with **NC** contact for end position detection
Pos. 7:
A: relay with **NO** contact
B: relay with **NC** contact
Pos. 8:
A: timer with **NO** contact
B: timer with **NC** contact
Pos. 9:
A: coil of a solenoid valve
B: coil of a relay
C: coil of a timer

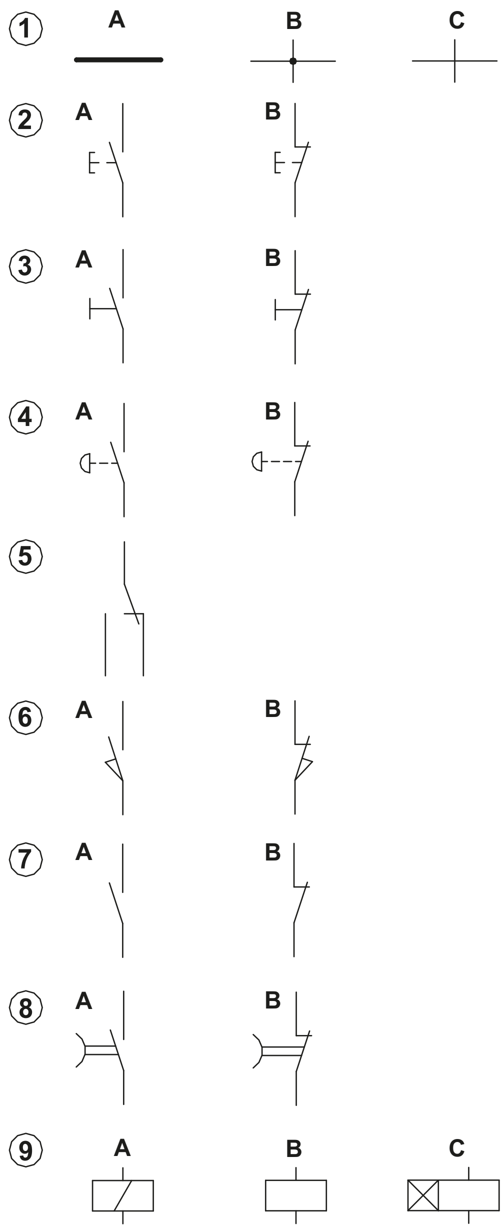


Fig. 1

Relay circuits

A relay is an electric component combined with one or more contacts, also with different functions. These are operated by means of a mechanism activated by a coil, changes its state, by either opening or blocking the passage.

Figure 2
Pos. 1:
A: the coil is de-energized the contact is **NC** and the electrical signal can pass;
B: the coil is energized and attracts the moving mechanism, which opens the contact. The electric signal can no longer pass.
Pos. 2:
A: the coil is de-energized, the contact is **NO** and the electrical signal does not pass;
B: the coil is energized and attracts the moving mechanism, which closes the contact. The electrical signal can now pass.
Pos. 3: in this case the relay has two contacts with different functions: one **NO** and one **NC**
A: the coil is de-energized, the electrical signal can only pass through the **NC** contact
B: the coil is energized and attracts the moving mechanism inverting the status of the contacts. The **NO** contact closes and the electrical signal can now pass, as the **NC** contact opens the electrical signal is interrupted.

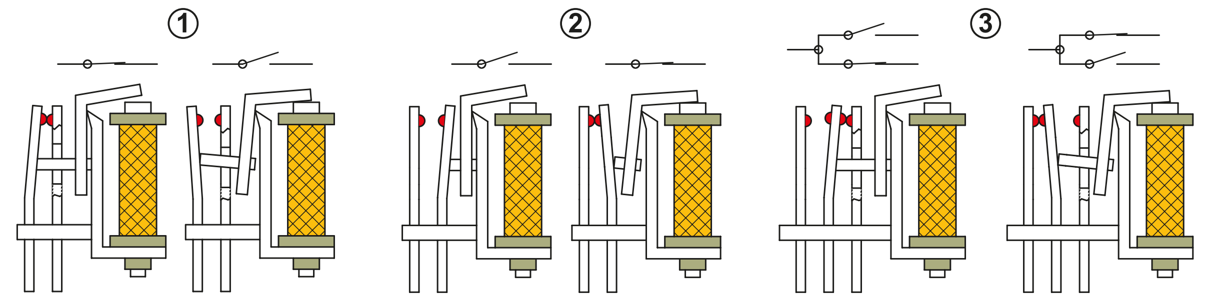


Fig. 2

Figure 3
Identity Function
Line 1: the **P1** button is connected to an **NO** contact. The output signal energizes the coil of relay **X** which is connected to the two **NO** contacts, **x** and **x$_1$**.
Line 2: contact **x** of relay **X** is connected, the output signal energizes coil **B1**.
Line 3: the contact **x$_1$** of the relay **X** is connected, this contact has no applied load.

In the circuit diagram illustrated below, closing contact button **P1** results in:
- the relay **X** energizes
- contacts **x** and **x$_1$** on **Lines 2** and **3** close
- At each activation of **P1**, the coil **B1** is energized

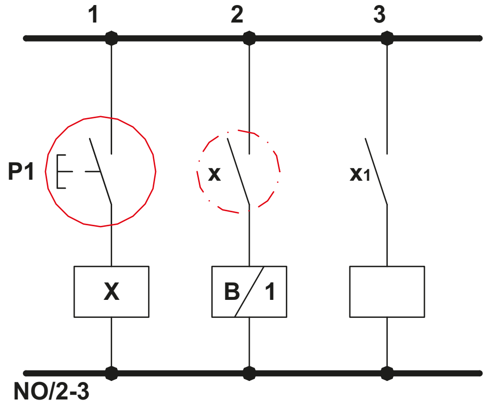


Fig. 3

Figure 4
Negation Function (inverter)
Line 1: the **P1** button is connected to an **NO** contact. The output signal energizes the coil of relay **Y** which has two **NC** contacts, **y** and **y$_2$**, and one **NO** contact, **y$_1$**.
Line 2: contact **y** of relay **Y** is connected, the output signal energizes coil **B2**. In this phase the coil is energized.
Line 3: **y$_1$** is connected to the contact of relay **Y**, this contact has no applied load.
Line 4: **y$_2$** is connected to the contact of relay **Y**, this contact has no applied load.

In the circuit, closing contact button **P1** results in:
- the **Y** relay energizes
- contacts **y** and **y$_2$** open
- contact **y$_1$** closes
- coil **B2** is de-energized

Each activation of **P1** de-energizes coil **B2**.

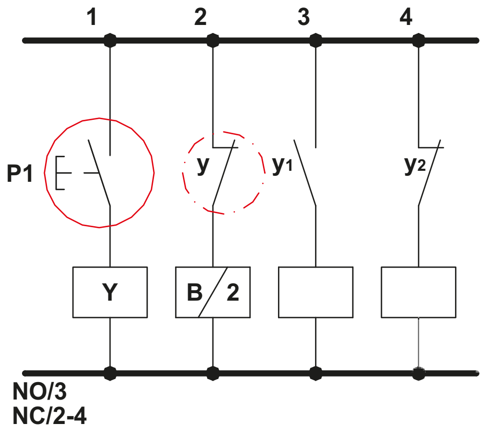


Fig. 4

Figure 5
Memory Function
It is possible to create this circuit using two different connections. By pressing briefly on push-button **P1**, the coil of relay **X** energizes as the **P2** contact button is closed. The contact **x** closes and keeps the relay energized even after the release of the push- button **P1**. To cancel the memory, briefly press push- button **P2**, which can be placed in both positions as illustrated in the drawing.

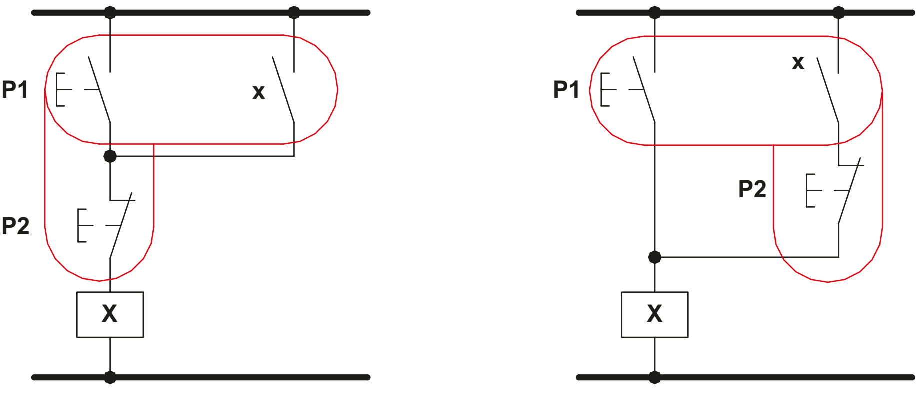


Fig. 5

Control systems

Upon analysis of the various electrical contacts, we examine how to incorporate them into a circuit.
In our example we assume the contact load is a solenoid of a solenoid valve.

In this first electro-pneumatic circuit example, the push buttons directly activate the solenoids. We will later observe that the commands act as Inputs on a PLC (Programmable Logic Controller), or activate the coil of a relay, they never act directly on the load. The load is connected to the contacts of the relay.

The **power** and **control** circuits are represented in an electro-pneumatic diagram.
In the **power** circuit the pneumatic components (cylinders and solenoid valves) are represented. In the **control** circuit, traditional electrical components (relays, contactors, contacts, and also the electrical parts of pneumatic components such as solenoids) are represented.

Figure 6
Activation of a monostable 5/2-way solenoid valve.
A: with the activation of the **P1** button, the **NO** contact closes, the electrical signal reaches and energizes solenoid **B1**. The solenoid valve changes over and allows the positive stroke of the piston rod/piston of the cylinder.
The duration of the activation on button **P1** corresponds to the duration of the electrical signal that energizes the solenoid **B1**. When releasing the **P1** button, the solenoid valve returns to its rest position and the cylinder completes the negative stroke.
B: the button **P1** has been replaced by selector switch **S1** which maintains the position given by the activation. When **S1** is activated, the **NO** contact closes, the electrical signal reaches and energizes solenoid **B1** The solenoid valve changes over and allows the positive stroke of the cylinder piston rod/piston. The negative stroke is only possible when the selector is repositioned.

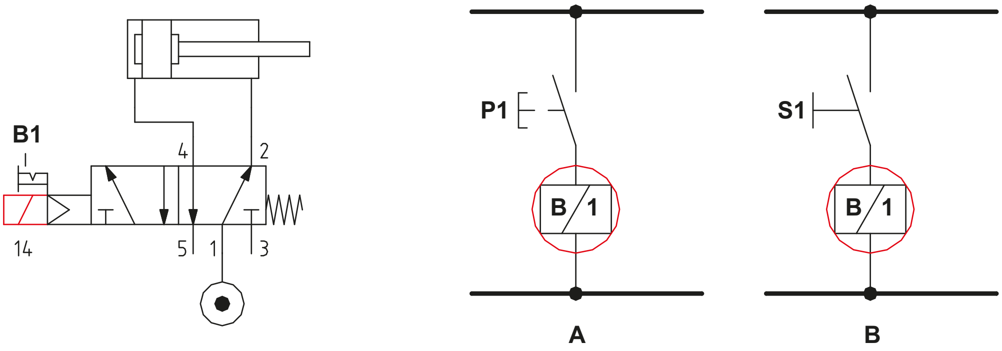


Fig. 6

Figure 7

Activation of a bistable 5/2-way solenoid valve.

A: buttons **P1** and **P2**, through **NO** contacts, are connected respectively to solenoids **B1** and **B2**. In this case, as the solenoid valve is bistable, a continuous signal on the solenoids is not required. If button **P1**, is pressed, the **NO** contact closes and an electrical signal energizes solenoid **B1** and the cylinder completes the positive stroke. When the button is released, the contact re-opens and the electrical signal is interrupted, the solenoid valve maintains its position however, repeating the same action on button **P2**, the negative stroke completes.

B: **P1** and **P2** have been replaced by selector **S** on which one **NC** contact and one **NO** contact are operated simultaneously. When the **NC** contact opens, the **NO** contact closes and vice versa.

This solution, even if anomalous in the sense of the bistable function of the valve ensuring the position of the spool, can be an advantage to use in the presence of strong vibrations that otherwise could change the status of the valve.

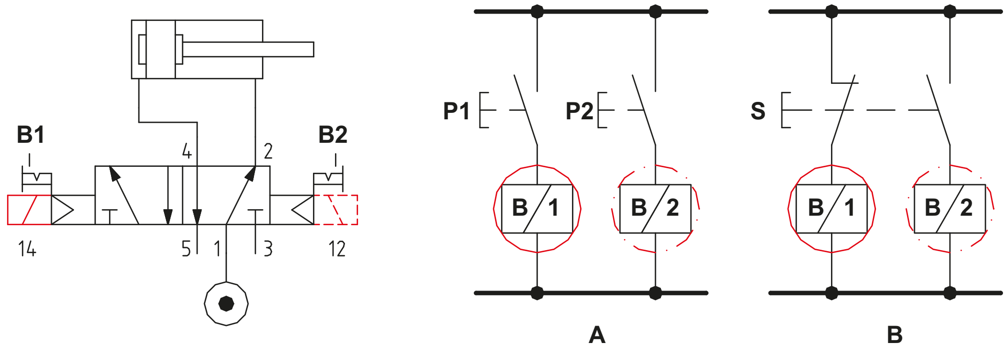


Fig. 7

The term "cycle" of a cylinder represents the period in which the piston rod/piston completes the positive and negative strokes. The term "sequence" refers to the set of cycles of numerous cylinders necessary to perform a given operation. Identification of: Logic lines, relays and their respective contacts.

Figure 8

Single cycle of a cylinder with a bistable 5/2-way solenoid valve.

Line 1: through the operation of the **I.C.** button (cycle start) the **NO** contact is closed, the signal passes and energizes the solenoid **B1**.

The **I.C.** button can be released. The solenoid valve changes over and the piston rod/piston completes the positive stroke.

Line 2: the piston rod/piston reaches and operates limit switch **a1**, the contact closes and energizes solenoid **B2**. The solenoid valve changes over and the piston rod/piston completes the negative stroke.

Figure 9

Single cycle of a cylinder with detection of the initial position, bistable 5/2-way solenoid valve.

Line 1: through the activation of the **I.C.** button (cycle start) the **NO** contact closes, the signal reaches the contact of limit switch **a0**, which is then operated, as the cylinder is in the initial position.

The signal energizes solenoid **B1**, the solenoid valve changes over and the piston rod/piston completes the positive stroke, the contact of limit switch **a0** is released and returns to its **NO** state.

The **I.C.** button can be released.

Line 2: the piston rod/piston reaches and activates limit switch **a1** the contact closes and energizes solenoid **B2**. The solenoid valve changes over and the piston rod/piston completes the negative stroke.

The procedure is the same as *Figure 8*, where the cycle only starts upon confirmation of the initial position with the limit switch **a0** activated.

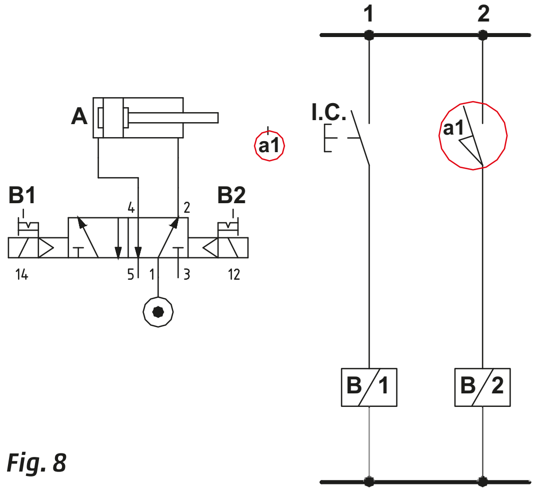


Fig. 8

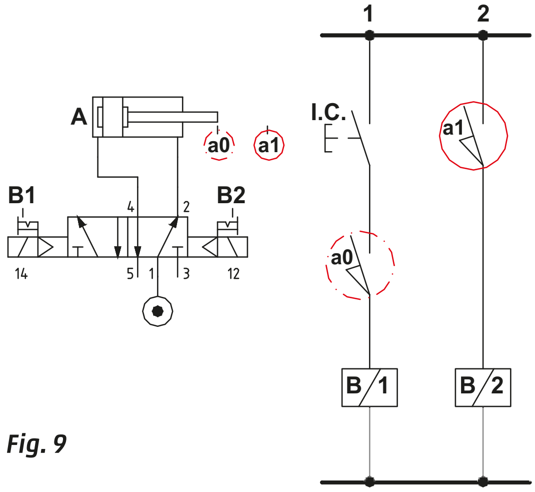


Fig. 9

Figure 10

Single cycle of a cylinder with detection of the initial position, monostable 5/2-way solenoid valve.

With this type of solenoid valve, the command of the **I.C.** button must be memorized for the cylinder to complete the entire stroke.
Line 1: by pressing the **I.C.** button in the presence of the limit switch **a0**, the signal reaches the solenoid **B1** of the valve in addition to energizing the coil of the relay **X**. The solenoid valve changes over and the piston rod/piston completes the positive stroke.
The contact **a0** of the limit switch is released and returns to the **NO** state.
Line 2: The **I.C.** button can be released as the command to the solenoid **B1** is latched through the contact **x** of relay **X**.
Line 3: once the positive end position has been reached, limit switch **a1** is activated and the contact is closed. The signal energizes the coil of relay **Y**, which opens the corresponding contact **y** on **Line 2**.
As solenoid **B1** is no longer energised, the solenoid valve repositions and the piston rod/piston completes the negative stroke.

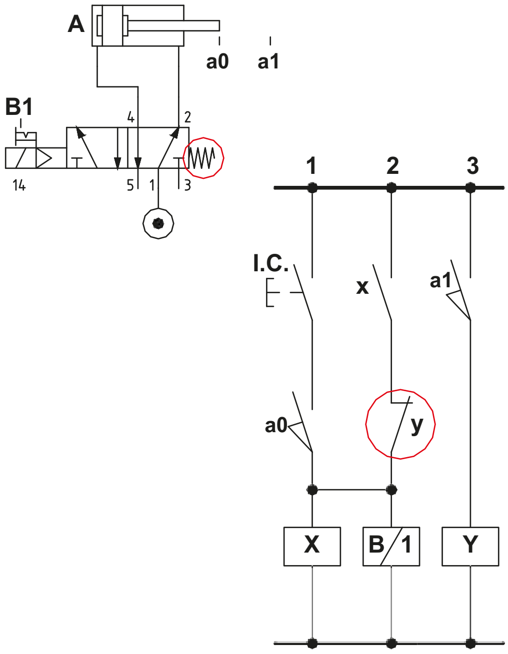


Fig. 10

Figure 11

Continuous cycle of a cylinder, bistable 5/2-way solenoid valve.

A cycle is considered continuous when it repeats automatically. Normally the position of the piston rod/piston of the cylinders in a machine are detected through magnetic proximity switches located on the cylinder tube or profile.
The amount of current that can pass through the contact of these sensors is limited and depends on the power consumption of the connected load.
To avoid problems with the sensors, the load in this case is determined by the solenoids, and this load is applied on the contacts **x** and **y** of the respective relays **X** and **Y**.
Line 1: the solenoids of the valve are de-energized, the button of End Cycle **F.C.** is in the **NC** position.
By pressing the **I.C.** button the signal energizes the coil of the relay **X**.
Line 2: the contact **x** of the relay **X** closes, latching **Line 1**, the **I.C.** button can now be released.
Line 3: the contact **x** in addition to latching **Line 1** passes the signal to the contact of the proximity switch **a0**. In this phase, the proximity switch is operated as the cylinder is in rest position. The signal then reaches and energizes solenoid **B1** of the valve.
The valve changes over, the piston rod/piston executes the positive stroke.
Line 4: the proximity switch **a0** is no longer operated, the piston rod/piston reaches the proximity switch **a1**. The signal energizes solenoid **B2**. The valve, no longer energized by solenoid **B1**, changes over, the piston rod/piston executes the negative stroke.

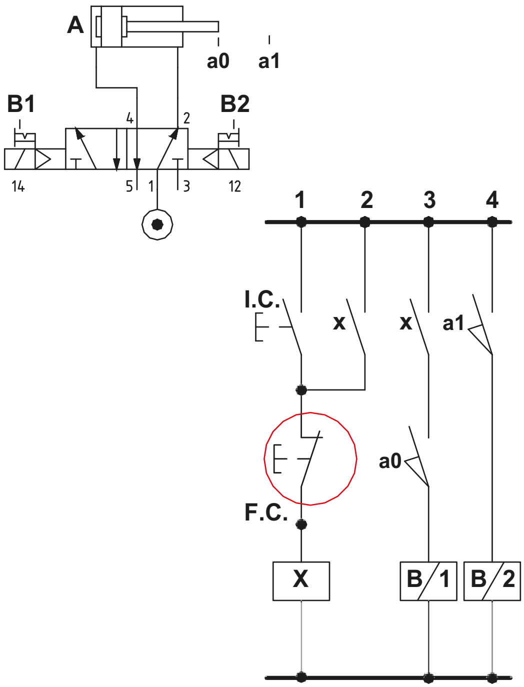


Fig. 11

Upon reaching start position, the proximity switch **a0** resumes operation, the coil of the relay **X** is re-energized, the signal on **Line 3** is still active, and with the closure of the limit switch, the signal from contact **a0** energizes solenoid **B1** The valve changes over and the cycle resumes. The **F.C.** (End of Cycle) button must be activated to terminate the cycle.

Electro-pneumatic circuit

Figure 12

Single cycle of a double acting cylinder with a bistable 5/2-way solenoid valve.

Line 1: the initial position of the cylinder is determined by the last received signal, in this case the signal which energized solenoid **B2** of the solenoid valve.

When pressing the **I.C.** start button, the electric signal reaches and energizes the solenoid **B1**.

The solenoid valve changes over and the piston rod/piston of the cylinder completes the positive stroke.

Line 2: once the positive end position has been reached, limit switch **a1** is activated, the contact closes and the electric signal energizes solenoid **B2**.

The solenoid valve repositions and the piston rod/piston of the cylinder completes the negative stroke, providing the **I.C.** button has been released.

By maintaining the **I.C.** button activated, the command to the solenoid **B1** blocks **B2**.

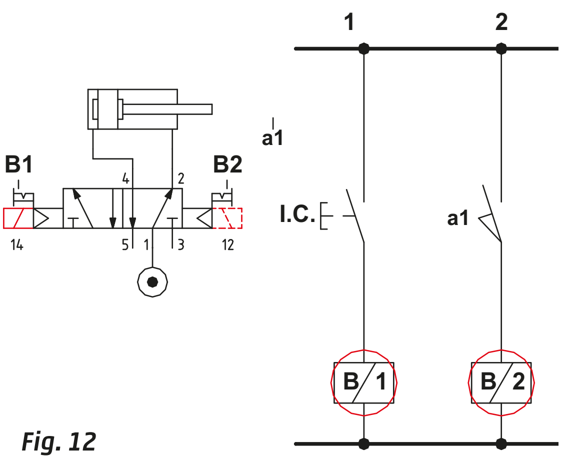


Fig. 12

Figure 13

Continuous cycle of a double acting cylinder with a monostable 5/2-way solenoid valve.

Line 1: to obtain a continuous cycle with a monostable solenoid valve and push button, the start command needs to be memorized, relay **X** is added to achieve this. When pressing the **I.C.** start button, the contact closes and the electrical signal reaches the contact of the end cycle **F.C.** button. As this contact is closed, the signal passes through to relay **X**, energizing the coil which closes the contact **x**. The contact **x** is connected in parallel with the **I.C.** button which can now be released. The designation **NO/1-2** below **Line 1** indicates that contact **x** is open and present on both **Line 1** and **Line 2**.

Line 2: contact **x** is closed, the contact of limit switch **a0** is closed, even though displayed as open, as it is operated by the cylinder; the signal energizes the coil of the relay **Y**. Contact **y** closes.

Through the connection between contact **a0** and relay **Y**, the signal also arrives at **Line 3**.

The designation **NO/3** below **Line 2** indicates that contact **y** is present on **Line 3** and is open.

Line 3: contact **y** is closed, also **z** is closed, the signal passes and energizes solenoid **B1**.

With **B1** energized, the piston rod/piston completes the positive stroke, limit switch **a0** no longer confirms the position of the piston. To avoid the coil of the relay **Y** de-energizes when its contact opens, this signal is latched.

Line 4: once limit switch **a1** has been reached and its contact closed, the coil of the relay **Z** is energized.

The contact **z** opens and solenoid **B1** de-energizes as it no longer receives a signal, the solenoid valve returns to its rest position.

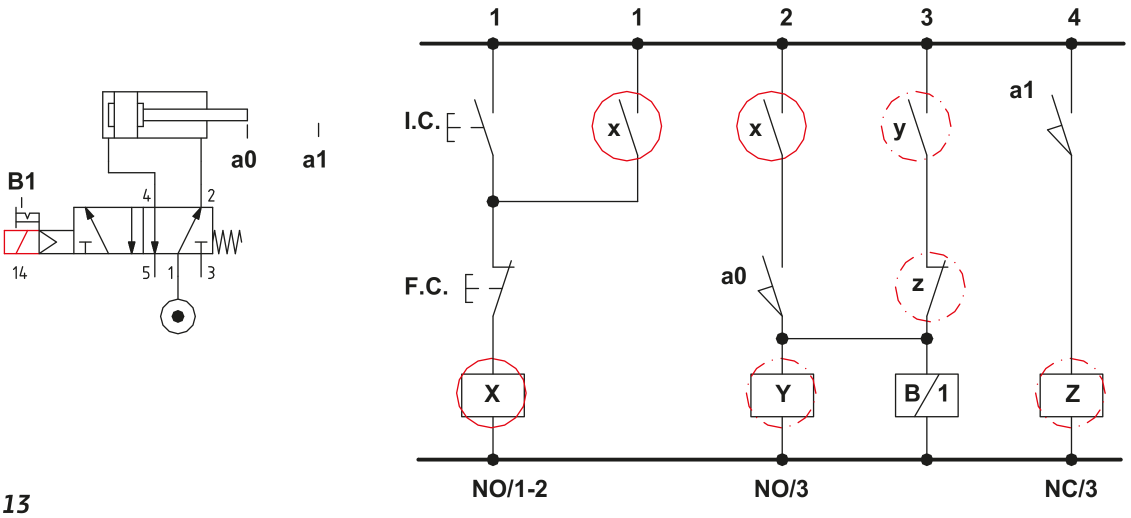


Fig. 13

When pressing the **F.C.** button, the coil of relay **X** no longer receives power supply:

- The piston rod/piston, carrying out its positive stroke reaches the end position then returns. When opening contact **x** on **Lines 1** and **2** the signal to the coil of the relay is also maintained by **y** on **Line 3**, the contact of limit switch **a1** is not activated, and contact **z** is closed.
  Once limit switch **a1** has been reached, its contact closes, the coil of the relay **Z** is then energized and contact **z**, by opening, interrupts the energizing of solenoid **B1**. The piston rod/piston returns.
- When activated during the negative stroke, the piston rod/piston stops once it has reached the final end position.

Realization of logic functions

Figure 14

YES function

Without relay: the contact of button **P1** is **NO**, when activated the signal passes and reaches the solenoid **B1**, which becomes energized.

With relay: the output signal from the contact of button **P1** is connected to the coil of relay **X**, which energizes, closing the contact **x**. The signal then passes and energizes solenoid **B1**.

In both cases, in the presence of P1, B1 is energized P1 = **B1**

NOT function

Without relay: the contact of the button **P1** is **NC**. When activated the signal is interrupted. The solenoid **B1**, which is directly connected to **P1** is de-energized.

With relay: the contact of button **P1** is **NO** , when activated the signal passes and reaches the coil of the relay **X**, which energizes, opening contact **x**. The signal is interrupted and solenoid **B1** is de-energized.

In the absence of P1, B1 is energized $\overline{\text{P1}}$ = **B1**

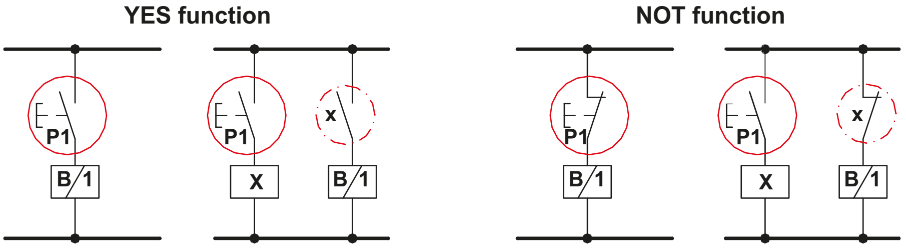


Fig. 14

Figure 15

AND function

Without relay: the contacts of the two buttons **P1** and **P2** are both **NO** and connected in series. By activating them and maintaining the command, the signal passes and solenoid **B1** is energized.

With relay: the contacts of the two buttons **P1** and **P2** are represented by contacts **x** and **y** of the relays **X** and **Y** respectively. These contacts are connected in series. By operating the buttons and maintaining the command, the coils of the two relays energize, closing their contacts. The signal reaches and energizes solenoid **B1**.

In the presence of both P1 and P2, B1 is energized P1 ∗ P2 = **B1**

OR function

Without relay: the contacts of **P1** and **P2** are connected in parallel and are both **NO**. The activation of one or both, allows the signal to pass and energize solenoid **B1**.

With relay: the contacts of the two buttons **P1** and **P2** are represented by contacts **x** and **y** of the relays **X** and **Y**, and are connected in parallel. The activation of one or both allows the signal to pass and energize the coil of the relay. The contact of the relay closes, the signal energizes solenoid **B1**.

In the presence of either P1 or P2, or both, B1 is energized P1 + P2 = **B1**

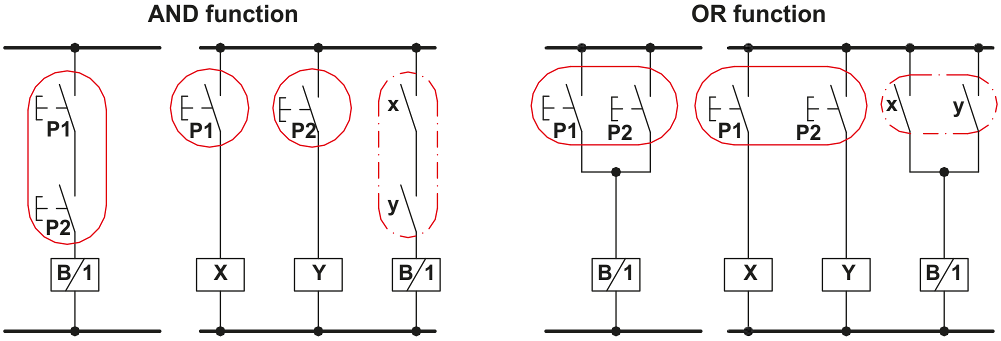


Fig. 15

Figure 16

NAND function

The NAND (NOT AND) function, is only possible when a relay is present.
When relay **X** is not energized, contact **x** is **NC** therefore solenoid **B1** is energized.
The **NO** contacts of **P1** and **P2** are connected in series, when both are activated the signal passes and energizes the coil of relay **X**, contact **x** opens and the solenoid **B1** is de-energized.

In the absence of either P1, P2 or both, B1 is energized $\overline{P1} * \overline{P2} = \mathbf{B1}$

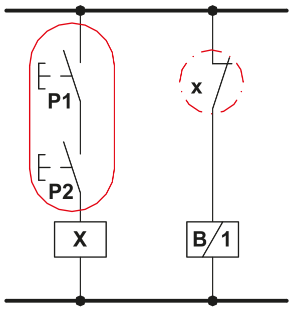
NOR function

The NOR (NOT OR) function is only possible in the presence of a relay.
When relay **X** is not energized, contact **x** is **NC**, solenoid **B1** is energized.
The **NO** contacts of **P1** and **P2** are connected in parallel, when either one or both are activated, the signal energizes the coil of relay **X**, contact **x** opens and solenoid **B1** is de-energized.

In the absence of P1 and P2, B1 is energized $\overline{P1} + \overline{P2} = \mathbf{B1}$

NAND function

P1	P2	B/1
0	0	1
1	0	1
0	1	1
1	1	0



NOR function

P1	P2	B/1
0	0	1
1	0	0
0	1	0
1	1	0

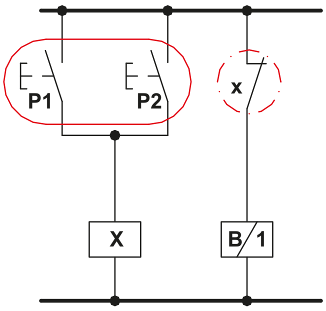


Fig. 16

Figure 17

Pos. 1: the conditions for the solenoid **B1** to be energised are:
P1 activated, the signal energizes the coil of relay **X**, which closes contact **x** and with **P2** not activated, contact **y** remains closed, the signal passes and energizes solenoid **B1**.

$$P1 * \overline{P2} = \mathbf{B1}$$

Pos. 2: the conditions for the solenoid **B1** to be energised are:
P1 activated, the signal energizes the coil of relay **X**, which closes its contact **x**. In this state the position of the other contacts have no influence.

Or

P2 activated, **P3** not activated, the signal energizes the coil of relay **Y**, which closes its contact **y**, contact **z** remains unchanged, the signal passes.

$$P1 + P2 + \overline{P3} = \mathbf{B1}$$

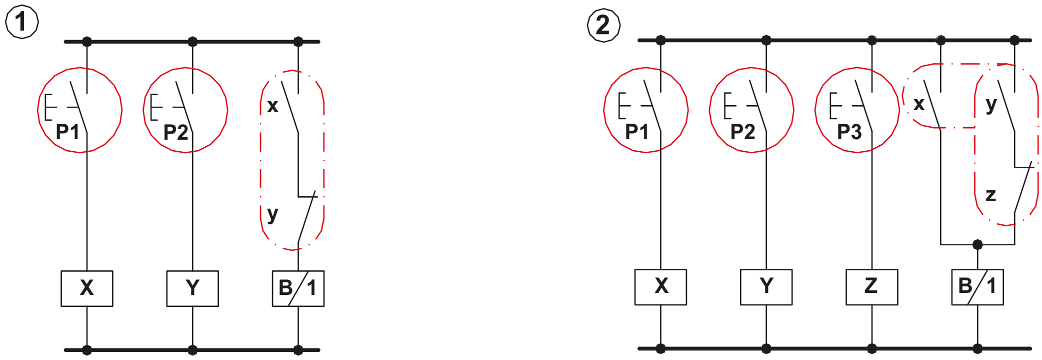


Fig. 17

Circuits with dual commands

In some situations it may be useful to have a second command in addition to the cycle start command, one which permits maintenance or adjustment of the individual actuators once the sequence has stopped.

Figure 18
Pos. 1: Controlling a double-acting cylinder with Bistable 5/2-way solenoid valve.
Line 1: when the **C.C.** (Continuous Cycle) button is pressed, the output signal reaches the closed End Cycle **F.C.**, button. It passes through, arriving at, and energizing the coil of relay **X**. Contact **x** of this relay, connected in parallel with the **C.C.** button, closes and latches the **C.C.** button which can now be released.
Line 2: also contact **x** on this line closes and the signal reaches limit switch **a0** which by detecting the position of the piston rod/piston at the negative end position, permits the signal to pass and energize solenoid **B1** of the solenoid valve. The solenoid valve changes over and the piston rod/piston executes the positive stroke, reaching position **a1**. With the release of the limit switch in position **a0** the contact opens and interrupts the passage of the signal to solenoid **B1**. Even in the absence of this command, the bistable solenoid valve maintains the position given by the last received signal.
Line 3: Once position **a1** has been reached, the corresponding limit switch is activated thereby closing the contact, allowing the signal to energize solenoid **B2**. The solenoid valve changes over and the piston rod/piston executes the negative stroke.

Once the position has been reached, limit switch **a0** re-activates, the signal is then free to pass (as the contact **X** is still closed), re-energizing solenoid **B1**, and the sequence repeats. With the release of switch limit **a1**, the signal to solenoid **B2** is interrupted.
By pressing the End Cycle **F.C.** button, relay **X** de-energizes and opens contact **x** on **Line 1** releasing the latch, the cylinder can only be restarted if the **C.C.** button is pressed again.

Pressing the Single Cycle **C.S.** (**Line 2**) while the piston rod/piston is at end position **a0** causes solenoid **B1** to energize.
The solenoid valve changes over, the piston rod/piston completes the positive stroke. Upon reaching limit switch **a1**, if the **C.S.** button is released, solenoid **B2** is energized to execute the negative stroke. Once the negative end position has been reached, the cylinder stops.
In the event of a power failure the piston rod/piston would complete the current stroke and then stop. If it were in the positive end position when the power is restored, it would return immediately to its starting position as signal **a1** energizes solenoid **B2**.

Note: The **C.S.** button can not be placed in parallel with contact **x** on **Line 1** and the **C.C.** button, as its activation would drive the coil of the relay **X**, to energize, cancelling the single cycle function. (Ref. circuit in the box).

Figure 18
Pos. 2: Control of a double-acting cylinder with a Monostable 5/2-way solenoid valve.
With this type of solenoid valve the **C.C.** and **C.S.** commands must be memorized for the duration of the positive stroke.
Line 1: by pushing and holding down the **C.C.** button, the signal reaches and passes through the contact of the **F.C.** button and energizes the coil of relay **X** thereby closing contact **x**. This contact, in parallel with the **C.C.** button latches. The **C.C.** button can then be released.
Line 2: also contact **x** on this line closes, the signal passes and reaches limit switch **a0**, which, by detecting the position of the piston rod/piston at the negative end position, allows the signal to energize solenoid **B1**, the signal also reaches the coil of relay **Y** on **Line 3**.
Line 3: when the coil of relay **Y** energizes, its respective contact **y** closes. As contact **z** is closed, the signal once again reaches the coil of relay **Y** and latches.
Line 4: with solenoid **B1** on **Line 2** energized, the piston rod/piston initiates its movement towards limit switch **a1**, which, once reached, allows the signal to reach the coil of relay **Z**.

When contact **z** opens, the coil of relay **Y** is de-energized. Opening contact **y** and releasing the latch interrupts the energizing of solenoid **B1**. The solenoid valve, due to the effect of the internal spring, returns to its rest position and the piston rod/piston completes the negative stroke. With the activation of the limit switch **a0**, the signal, still active on **Line 2**, will once again reach solenoid **B1** and the coil of relay **Y**, and a new sequence begins.

By pressing the **F.C.** button, the coil of relay **X** de-energizes, the contact **x** on **Line 2** opens and interrupts the energizing of solenoid **B1** and the coil of relay **Y**.

The Single Cycle button **C.S.** (**Line 2**) is in parallel with contact **x** and repeats the flow illustrated above by stopping the cycle when the piston rod/piston reaches the negative end position again. For a new Single Cycle the **C.S.** button must be pressed.

In the event of a power failure, the cylinder immediately returns to the start position. The restart is obtained by pressing the **C.S.** or **C.C.** buttons.

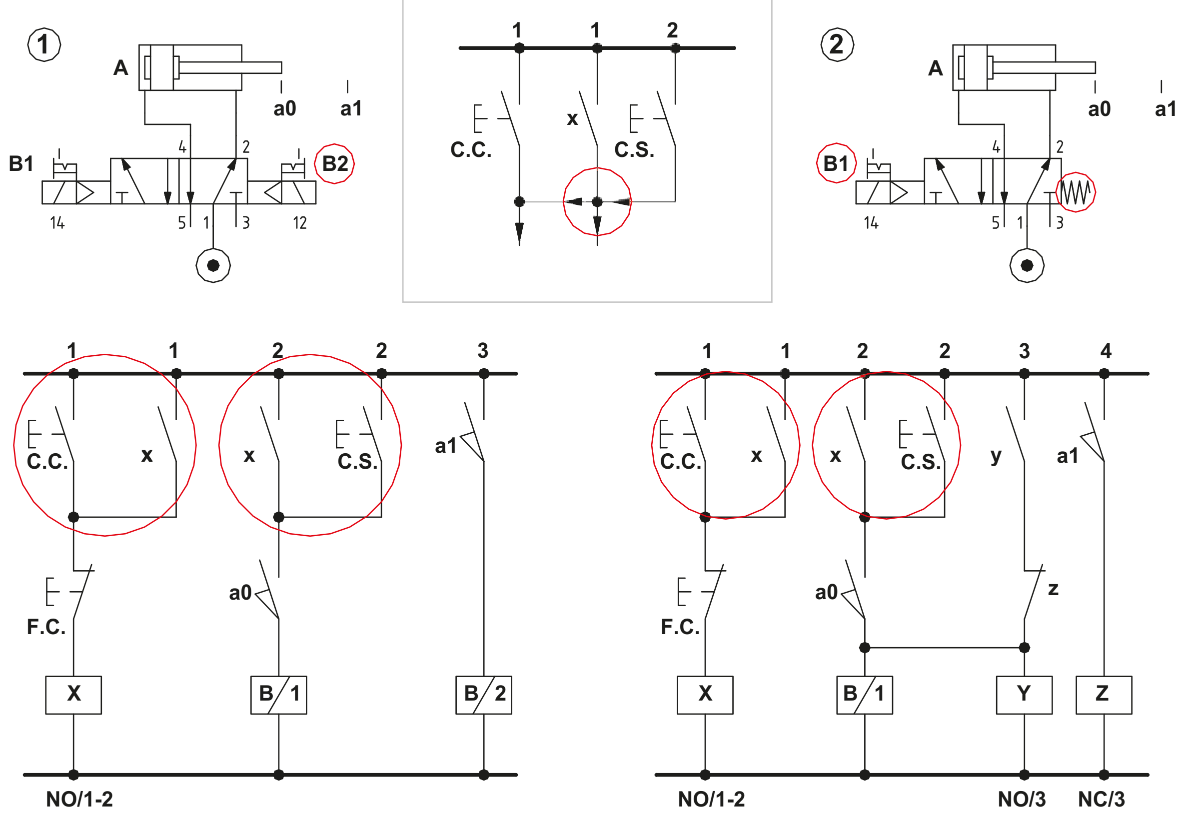


Fig. 18

In this section we analyze two circuit solutions for the realization of a sequence with the continuous cycle command (more commonly defined as Automatic Cycle, AUT) and the single cycle (more commonly defined as manual, Man). As in the previous case, we use a single cylinder for convenience.

Figure 19
Pos. 1: manual control for both strokes of the cylinder. The selector chooses the mode of operation i.e. **AUT.** or **Man.** mode.

AUT mode.

The buttons **Man A +** and **Man A –** are disabled.
To start the cycle, the operator must press the **I.C.** button, permitting the signal to reach the contact **F.C.** which is closed in this phase. The signal passes through **F.C.** and energizes the coil of relay **X**. The contacts **x** and **x1** on **Lines 1** and **2** close.

$$X = AUT \ast I.C. \ast F.C.$$

Line 1: with the closing of contact **x** the **I.C.** command latches.
Line 2: with the contact **x1** closed, the signal reaches limit switch **a0**. In this state the contact is closed, as the limit switch is activated by the presence of the piston rod/piston at the negative end position. The signal passes, arriving at solenoid **B1** of the valve, which changes over to execute the positive stroke of the piston rod/piston of the cylinder.

$$B1 = x1 \ast a0$$

Line 3: once the positive end position has been reached, limit switch **a1** is activated and, by closing, allow the signal to pass and energize solenoid **B2**.
As limit switch **a0** is no longer activated, solenoid **B1** is not energized. The now energized solenoid **B2**, changes the solenoid valve over to execute the return stroke. When limit switch **a0** closes the cycle restarts.

$$B2 = \overline{a0} \ast a1$$

Figure 19

Manual Mode

The switch in this position will disable the entire circuit linked to the automatic mode, the only active remaining buttons are **Man A +** and **Man A –**.

Their activation device is stable so as to avoid the movement of the cylinder in the event of an accidental activation of the other device.

$$B1 = \overline{AUT} \ast \text{Man A} +$$

$$B2 = \overline{AUT} \ast \text{Man A} -$$

Pos. 2: automatic return of the cylinder from the positive position during manual operation.

Line 1: with the activation of the **AUT** button, the signal passes the contact of button **F.C.** (being **NC**) and energizes the coil of relay **X**. The contact **x** closes, latching the AUT command.

Relay **X** has three contacts, two of which are **NO** (**x** and **x1**) and one **NC** (**x2**).

$$X = AUT \ast I.C.$$

Line 2: contact **x1** is closing, permitting the electrical signal to reach the **I.C.** button, which once activated, allows the signal to reach limit switch **a0**. In this phase the contact of **a0** is closed as it detects that the piston rod/piston is located in this position, the signal passes, energizing solenoid **B1**. The solenoid valve changes over and the piston rod/piston initiates the positive stroke.

$$B1 = x1 \ast I.C. \ast a0$$

Line 3: upon arriving at limit switch **a1** the contact closes and the signal energizes solenoid **B2**. The solenoid valve changes over and reverses the movement. This is possible as the piston rod/piston releases limit switch **a0** during the positive stroke, interrupting the signal to solenoid **B1**.

$$B2 = \overline{a0} \ast a1$$

With the reversal in direction of movement of the cylinder, **a0** closes again and the cycle repeats.

The **F.C.** command interrupts the latching of AUT and the cycle stops, the contact **x2** returns in the closed position and allows the activation of the selector **Man A +**. As long as this command remains active it maintains coil **B1** energized and the cylinder remains in the positive end position. With its removal, the signal on **Line 3** passes, and energizes the solenoid **B2** reversing the movement of the piston rod/piston.

$$B1 = \overline{AUT} \ast x2 \ast \text{Man A} +$$

$$B2 = \overline{AUT} \ast x2 \ast \overline{\text{Man A} +}$$

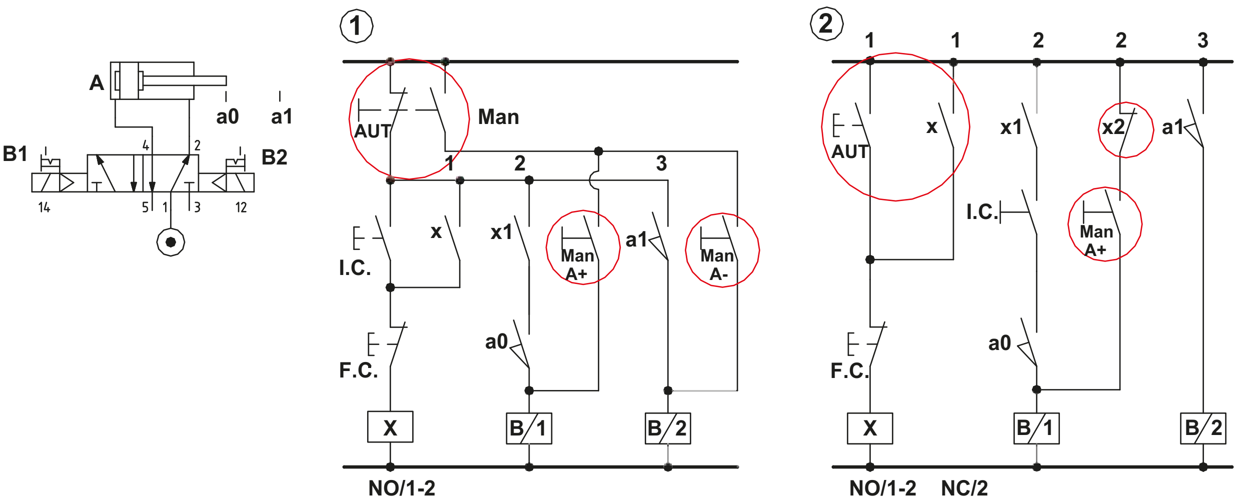


Fig. 19

Emergency control

As previously noted with pneumatic circuits, the emergency command can be executed in a variety of ways.
The emergency device is a manually operated contact, although in this case it is not a valve but an electrical contact, (generally **NC**). The opening of this contact interrupts the power supply to the circuit, (the main circuit and/or logic circuit located downstream from the command).

The **emergency** control may be utilized in the following ways:

- Stop during Cycle with restart after the command is removed. The system will restart from the stopped position.
- Stop during Cycle with restart after removing or resetting the command.
  The system can restart from either the stopped or initial position, with the reset command which repositions the piston rod/pistons of all the actuators to the cycle start position.
- Immediate repositioning of the piston rod/piston groups. The monostable 5/2-way solenoid valve with spring return is used.
  Restarts from the initial start position.
- Stops the piston rod/piston of the actuators in their present positions at the moment the EM is activated. 5/3-way CC solenoid valves are employed. The system can restart from its stopped or initial position with the reset command which repositions the piston rod/pistons of all the actuators to the cycle-start position.
- Completion of the strokes and stop at the end positions. In this case bistable 5/2-way solenoid valves are used.
  The system can restart from the current or initial position with the reset command which repositions the piston rod/pistons of all the actuators to the start- cycle position.

The **Reset** phase is established by a return sequence, i.e. by repositioning (the various devices) back to the start position. It is at the discretion of the machinery/equipment designer to select the most suitable emergency functions based upon the required safety conditions.
We examine a circuit comprising two double acting cylinders controlled by a bistable 5/2-way solenoid valve.

Figure 20
Pos. 1: Emergency Stop during Cycle function.
The cycle develops as observed in previous paragraphs. Activating the **EM** interrupts the power to all the limit switches of the system thereby releasing the latching of relay **X**. The piston rod/pistons of the cylinders terminate their current stroke and the cycle stops. Removing the **EM** command powers the limit switches and the cycle restarts, stopping after the last phase. As relay **X** is no longer latching, the **I.C.** button must be pressed to restart the cycle.

$$A+ = B1 = \overline{EM} \ast I.C. \ast b0$$

$$B+ = B3 = \overline{EM} \ast a1$$

$$A- = B2 = \overline{EM} \ast b1$$

$$B- = B4 = \overline{EM} \ast a0$$

Pos. 2: Stop during Cycle, restart from the Stop position or after Reset.
The connection of the **EM** command has been modified with respect to the previous case. When activated the cycle stops, leaving the piston rod/piston to finish its stroke, the operator can then decide how to proceed.

By removing the **EM** command, the limit switch once again has power and the sequence restarts, stopping after the last phase completes. As there is no latching relay to restart **X** it is necessary to press the **I.C.** button.

If the **EM** command is maintained, the actuators can return to their original positions via the **Reset** command, which by being activated energizes the coil of relay **Y**, closing contacts **y** and **y1**, energizing solenoids **B2** and **B4** changing over their respective solenoid valves, reposition the piston rod/piston of cylinder **A** and **B** in the negative end position. To restart the cycle, the **EM** command must be removed and the **I.C.** activated.

$$A+ = B1 = \overline{EM} \ast I.C. \ast b0$$

$$B+ = B3 = \overline{EM} \ast a1$$

$$A- = B2 = \overline{EM} \ast b1 + EM \ast Reset$$

$$B- = B4 = \overline{EM} \ast a0 + EM \ast Reset$$

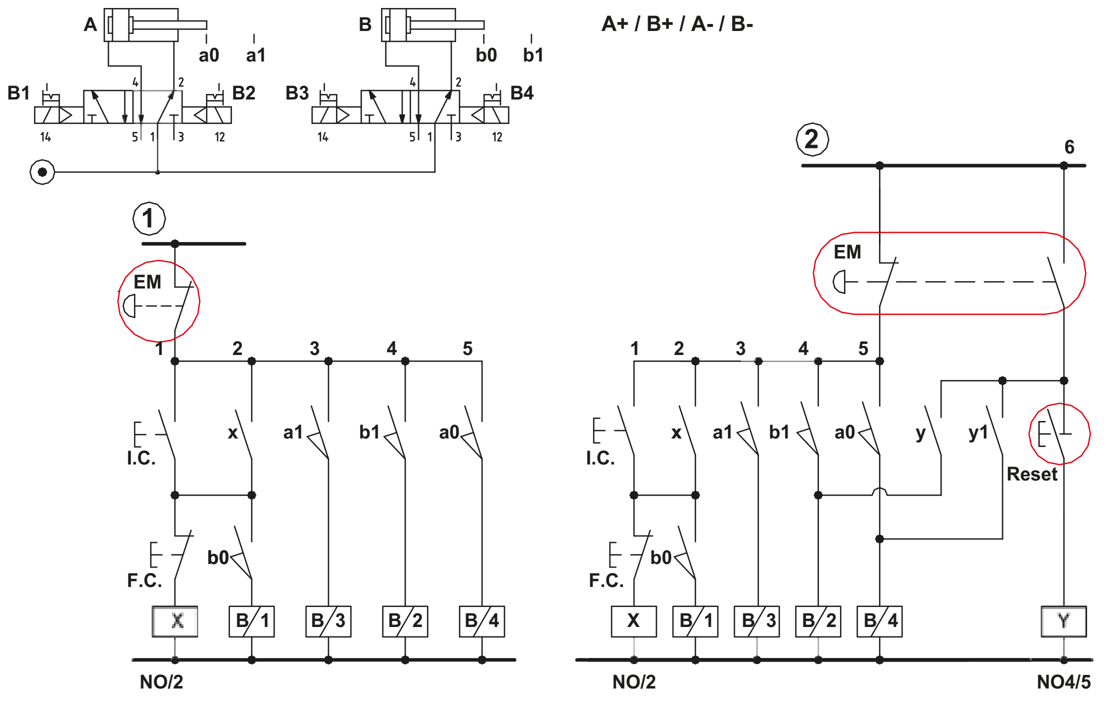


Fig. 20

Stop and re-positioning of the cylinders

As mentioned in the previous paragraph, the safety condition depends on the type of system used. In a pneumatic press for example, the safety condition requirement is a free working area, normally achieved by exhausting the compressed air supply from the rod lock. On a gripper or suction cup however, the compressed air supply must be maintained so as to hold the component in its position.
Depending on how the EM command is connected, it is possible to manage the movement of the cylinders, e.g. intervening even before they have reached the end position of their stroke.

Figure 21
The diagram below demonstrates two cylinders operated by their respective bistable 5/2-way solenoid valves. To prevent the piston rod/pistons from reaching their end positions and reversing their stroke in the presence of the EM command, it is necessary for the EM control to perform the following functions simultaneously:

- cut power from the control lines of the solenoid valves
- send the command to energize the solenoid valves - so they charge over and the actuators adopt their initial positions.

The EM command, in addition to removing power from all the limit switches, permits the passage of the electric signal to the coil of relay **Y**, energizing it, and thereby closing contacts **y** and **y1**.
With the closure of **y** and **y1**, solenoids **B2** and **B4** are energized. The solenoid valves reposition the piston rod/piston by changing over. However, this solution may not be fully effective. In the absence of an electric current, it will not be possible to change over the solenoid valves to reposition the cylinders which would complete their current stroke and then stop. When using monostable solenoid valves, the outcome is different. The internal spring in the valve causes the repositioning of the actuators if the electrical signal on the respective solenoids were to be interrupted through the EM command or a cut in the electrical supply.

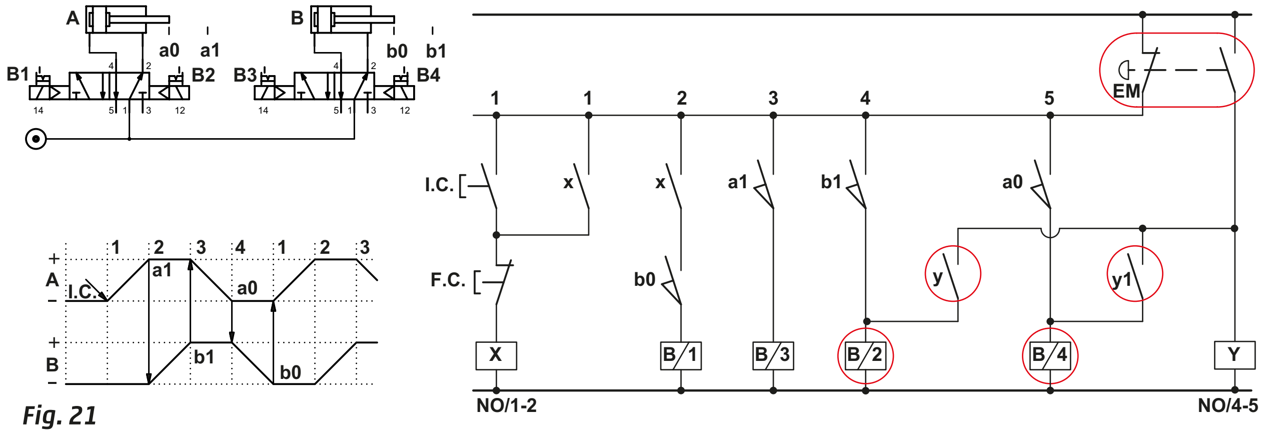


Fig. 21

Figure 22

Bistable solenoid valves are replaced with monostable solenoid valves. The circuit is simplified for the EM command, but is complicated with regards to the development of the sequence under normal conditions.

Three latching circuits must be introduced in order to maintain the electrical signal to charge over the monostable solenoid valves. The sequence develops as previously. The latching on the various lines have the following functions:

Line 1: contact **x** is latching the **I.C.** command.

Line 2 and **3:** contact **y** keeps the solenoid B1 energized, also when contact **b0** is open.

By energizing solenoid **B1** the piston rod/piston of cylinder **A** completes the positive stroke releasing limit switch **a0**. In the absence of latching, the piston rod/piston would return to the starting position without having completed the stroke.

Line 4 and **5:** once position **a1** has been reached, the coil of relay **U** and the solenoid **B3** are energized.

By energizing solenoid **B3** the piston rod/piston of cylinder **B** completes the positive stroke, releasing limit switch **b0**.

Contact **u** maintains coil **B3** energized also when contact **a1** is open.

With limit switch **b1** activated, the coil of the relay **Z** energizes, opening contact **z** and de-energizing solenoid **B1**.

Line 6: upon reaching position **b1**, contact **z** on **Line 3** opens, solenoid **B1** is no longer energized; the piston rod/piston of the cylinder **A** completes the negative stroke, releasing limit switch **a1**.

Line 7: upon reaching position **a0** contact **v** on **Line 5** opens, solenoid **B3** is no longer energized; the piston rod/ piston of the cylinder **B** completes the negative stroke, releasing limit switch **b1**.

By activating the EM command the electric power to both the buttons and limit switches is cut. The solenoid valves are no longer energized and therefore allow the repositioning of the piston rod/pistons of cylinders **A** and **B**.

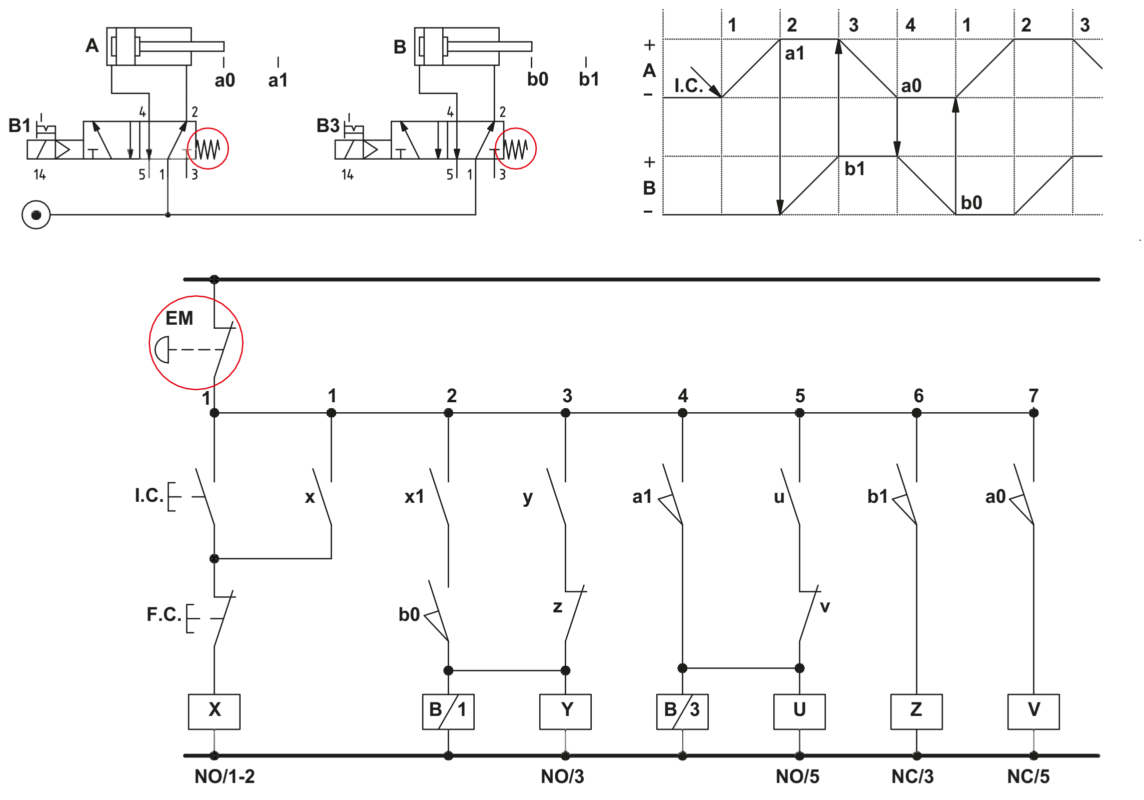


Fig. 22

Multiple cylinder cycle

In previous sections, we analyzed EM devices and possible circuit solutions.

In the following paragraphs, we address the required safety conditions for the cycle below:

A +	/	B +C –	/	A –	/	B –	/	C +
1		2		3		4		5

The letters correspond to the cylinders and their movement through the various Phases.

Figure 23
Phase 1: stroke **A +**
The safety condition required to execute this stroke; the piston rod/piston of cylinder **C** must have completed the positive stroke.
Line 1: in order to energize solenoid **B1** of the solenoid valve, the contact of limit switch **c1** must be closed, contact **x** must be closed and at least one of the two buttons **P1** or **P2** must be activated.
By energizing **B1**, the solenoid valve changes over and the piston rod/piston of cylinder **A** completes the positive stroke.
An eventual activation of the manual device on solenoid **B3** (solenoid valve of cylinder **B**), modifying the condition required of contact **x**, does not allow, even with the activation of buttons **P1** or **P2**, to start the cycle.
The equation for this motion is:

$$(P1+P2) \ast c1 \ast \overline{b1} = \mathbf{A\,+}$$

Phase 2: stroke **B + C –**
As the piston rod/piston of cylinder **A** initiates its movement, buttons **P1** and **P2** can be released.
Line 2: when the positive end position has been reached and limit switch **a1** activated, solenoids **B3** and **B6** are energized, their respective solenoid valves change over permitting the **B +** and **C –** strokes.
The equation for this motion is:

$$a1 = \mathbf{B + C\,–}$$

The safety condition required to proceed to the next step; the piston rod/piston of cylinders **B** and **C** must have completed the stroke.

Phase 3: stroke **A –**
Line 3: the closing of contacts **x1** and **y**, connected in series and both **NO**, ensures that the piston rod/piston of cylinders **B** and **C** reached their positions in the previous phase.
Solenoid **B2** is energized to effectuate the return of the piston rod/piston of cylinder **A**.
The energizing of solenoid **B1**, opposite to **B2** is interrupted as both limit switch **c1** and contact **x** have inverted their state.
The equation for this motion is:

$$b1 \ast c0 = \mathbf{A\,–}$$

The safety condition required to proceed to the next step; the piston rod/piston of cylinder **A** must have completed the stroke.

Phase 4: stroke **B –**
Line 4: the closing of contact **a0** ensures that cylinder **A** reached its position in the previous phase. Solenoid **B4** of the solenoid valve is energized, it changes over and the piston rod/piston of cylinder **B** returns. This operation is possible due to the absence of a signal to solenoid **B3**, as limit switch **a1** is interrupted. The relevant equation is:

$$a0 = \mathbf{B\,–}$$

The safety condition required to proceed to the next step; the piston rod/piston of cylinder **B** must have completed the stroke.

Phase 5: stroke **C +**
Line 5: the closing of contact **b0** ensures that the piston rod/piston of cylinder **B** reached its position in the previous phase. Solenoid **B5** of the valve is energized, with the changing over of the solenoid valve, the piston rod/piston of cylinder **C** completes the positive stroke. This operation is possible due to the absence of a signal to solenoid **B6**, as limit switch **a1** is interrupted.

The equation for this motion is:

b0 = **C +**

When end position **c1** is reached, return to **Phase 1** and the cycle resumes.

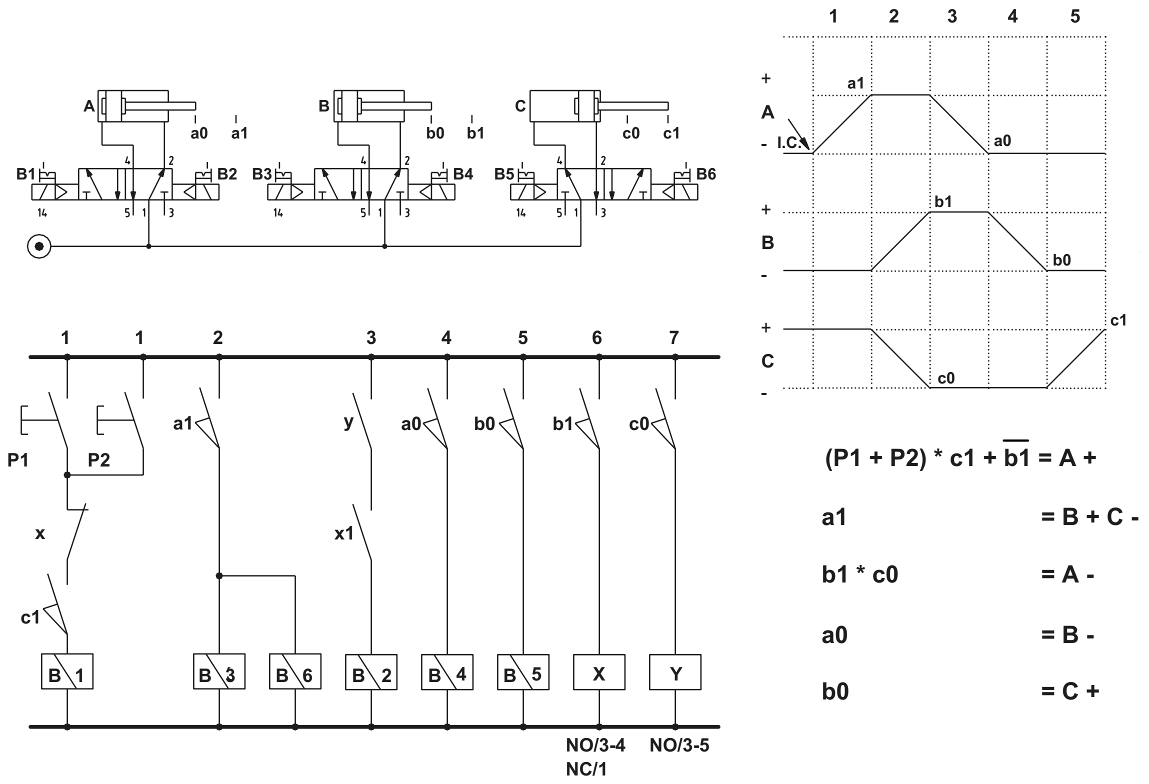


Fig. 23

We develop the previous sequence using the continuous cycle function and replacing the solenoid valve of cylinders **A** and **B** with monostable valves, while the solenoid valve of cylinder **C** remains bistable as it is activated for more than one phase. The two buttons **P1** and **P2** are replaced by the **I.C.** button.

The cycle to be realised is:

A +	/	B +C –	/	A –	/	B –	/	C +
1		2		3		4		5

Figure 24
Phase 1: stroke **A +**
The safety condition required to carry out this stroke; the piston rod/piston of cylinder **C** must have completed the positive stroke.
Line 1: when the button **I.C.** is activated, as contact **c1** of the limit switch and the **F.C.** button are closed, the coil of relay **X** energizes and, via contact **x**, the **I.C.** latches.
Line 2: solenoid **B1** of the valve energizes, the valve changes over, the piston rod/piston of cylinder **A** completes the positive stroke. The equation for this motion is:

I.C. * c1 = **A +**

Figure 24
Phase 2: stroke **B + C –**
Once the piston rod/piston of cylinder **A** initiates its movement, the **I.C.** button can be released.
Line 3: when limit switch **a1** has been reached, the coil of relay **Z** energizes.
Line 4: contact **z** closes and, via **k**, latches the coil of relay **Z**.
Line 5: contact **z1** closes and solenoids **B3** and **B6** energize, the solenoid valves change over and piston rod/piston of cylinders **B** and **C** complete their respective strokes.
The equation for this motion is:

a1 = **B + C –**

Phase 3: stroke **A –**
Line 6: once strokes **B +** and **C –** have stopped, and with the activation of their respective limit switches **b1** and **c0**, the coil of the relay **Y** energizes.
Line 2: contact **y** opens and solenoid **B1** is de-energized. The piston rod/piston of cylinder **A** completes the negative stroke. The equation for this motion is:

b1 * c0 = **A –**

Phase 4: stroke **B –**
Line 7: when limit switch **a0** has been reached, the coil of relay **K** energizes.
Line 4: the latching of relay **Z** is interrupted.
Line 5: contact **z1** opens and solenoids **B3** and **B6** de-energize. As there is no signal on **B3** the monostable solenoid valve of cylinder **B** returns. The piston rod/piston of cylinder **B** completes the negative stroke.
The equation for this motion is:

a0 = **B –**

Phase 5: stroke **C +**
Line 8: when limit switch **b0** has been reached, the solenoid **B5** energizes. The piston rod/piston of cylinder **C** completes the positive stroke.
The equation for this motion is:

b0 = **C +**

Contact **c1** closes and the sequence restarts. Pressing the **F.C.** button disables the cycle restart.

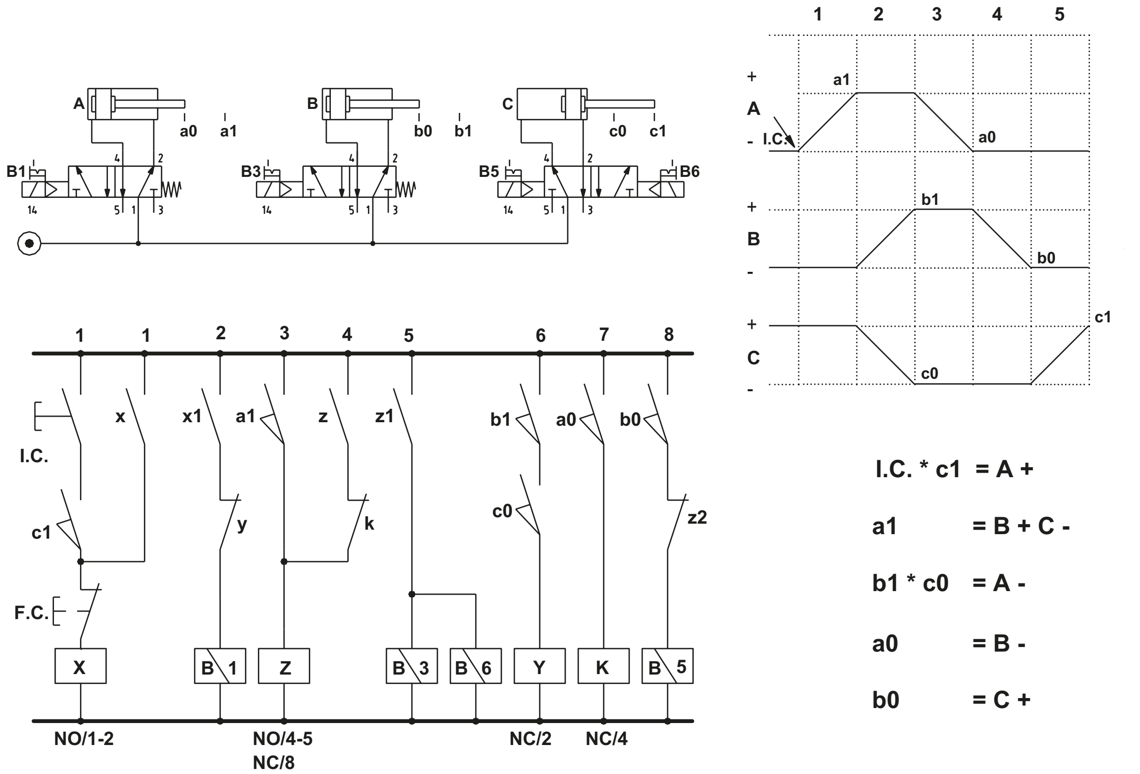


Fig. 24

Sequences with blocking signals

In this section we analyze how to construct electro pneumatic diagrams with blocking signals and also here we use memory circuits to control the duration of these blocking signals.

We examine the following cycle:

A +	/	B +	/	B –	/	A –
1		2		3		4

Figure 25
Observing the flow chart, it is possible to detect blocking signals that are generated by limit switches:

- **a1**: activated by the positive stroke of cylinder **A**, it enables **Phase 2** for the positive stroke of cylinder **B** however obstructs its negative stroke during **Phase 3**.
- **b0**: activated by cylinder **B** in rest position, it enables **Phase 4** for the negative stroke of cylinder **A** however obstructs the positive stroke during **Phase 1**.

Phase 1: stroke **A +**
The safety condition required to execute this stroke; the piston rod/piston of cylinder **A** must have completed its negative stroke.
Line 1: with the activation of the **I.C.** button, the coil of relay **X** energizes and, via contact **x**, the **I.C.** latches.
Line 2: contacts **x1** and **a0** are closed, both solenoid **B1** of the solenoid valve and the coil of relay **Y** on **Line 3** energize. The solenoid valve changes over and the piston rod/piston of cylinder **A** completes the positive stroke. The command to solenoid **B1**remains active until the coil of relay **Y** is energized.
The equation for this motion is:

$$\text{I.C.} * a0 = \mathbf{A+}$$

Phase 2: stroke **B +**
Line 3: The signal of **Line 2** energizes the coil of the relay **Y** activating contact **y**, latching the signal on solenoid **B1**.
Line 4: upon reaching limit switch **a1**, via contact **z1**, solenoid **B3** energizes, the valve changes over allowing the piston rod/piston of cylinder **B** to complete the positive stroke.
The output signal from limit switch **a1** acts as a blocking signal on cylinder **B** as it is present during both of its strokes. The equation for this motion is:

$$a1 = \mathbf{B+}$$

Phase 3: stroke **B –**
Line 5: upon completion of the positive stroke, cylinder **B** activates limit switch **b1** which energizes solenoid **B4** of the valve.
Line 6: solenoid **B4** and the coil of relay **Z** energize simultaneously, inverting the state of all the contacts **z**, **z1** and **z2**. The opening of contact **z** on **Line 3** interrupts the latching of relay **Y** and consequently interrupts the energizing of solenoid **B1** of the valve. The opening of contact **z1** on **Line 4** de-energizes of solenoid **B3** of the valve. The piston rod/piston of cylinder **B** can now execute the negative stroke.
The equation for this motion is:

$$b1 = \mathbf{B-}$$

Phase 4: stroke **A –**
Line 7: upon the completion of the negative stroke, cylinder **B** activates limit switch **b0** which energizes solenoid **B2**. The piston rod/piston of cylinder **A** can now execute the negative stroke. The equation for this motion is:

$$b0 = \mathbf{A-}$$

Once the negative stroke has been completed and limit switch **a0** activated, the cycle resumes automatically.
By pressing the **F.C.** button, the latching of relay **X** is interrupted therefore eliminating the possibility to energize solenoid **B1**, the cycle therefore does not restart.

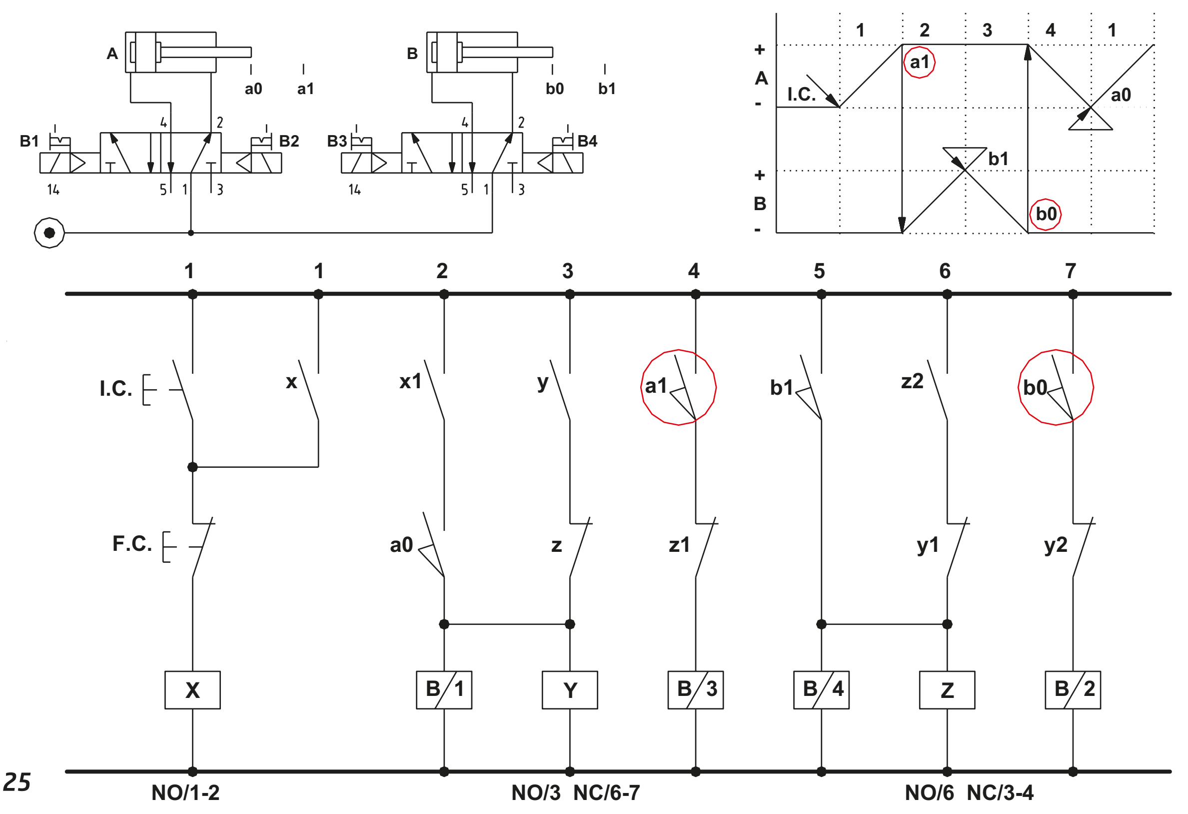


Fig. 25

In this example we construct a circuit comprising three cylinders, the cycle is:

A +	/	B +	/	B –	/	C +	/	C –	/	A –
1		2		3		4		5		6

Cylinder **A**: remains in a definite position (positive end position) during **Phases 2**, **3**, **4** and **5** here it is preferable to use a bistable solenoid valve.

Cylinder **B**: is only active during **Phase 2** it is preferable to use a monostable solenoid valve.

Cylinder **C**: is only active during **Phase 4**, it is preferable to use a monostable solenoid valve.

Blocking signals generated by limit switches can be detected by observing the flow chart:
- **a1**: activated by the positive stroke of the cylinder **A**, it enables **Phase 2** for the positive stroke of cylinder **B** however obstructs the negative stroke during **Phase 3**.
- **b0**: activated by cylinder **B** in the rest position, it enables **Phase 4** for the positive stroke of cylinder **C** however obstructs the negative stroke during **Phase 5**.
- **c0**: activated by cylinder **C** in the rest position, it enables **Phase 6** for the negative stroke of cylinder **A** however obstructs the positive stroke during **Phase 1**.

Figure 26
Phase 1: stroke **A +**
The safety condition required to execute this stroke; the piston rod/piston of cylinder **A** must have completed the negative stroke.
Line 1: with the activation of the **I.C.** button, the coil of relay **X** energizes and, via the closure of its contact **x** the **I.C.** latches.
Line 2: contacts **x1** and **a0** are closed, solenoid **B1** energizes and the valve changes over, the piston rod/piston of cylinder **A** executes the positive stroke.
Line 3: in addition to solenoid **B1**, the coil of relay **Y** also energizes and latches due to the closure of its contact **y**. The signal to solenoid **B1** remains active as long as the relay **Y** coil is energized.

Phase 2: stroke **B +**
Line 4: contacts **a1** and **y1** are closed, the solenoid **B3** of the valve energizes, the valve changes over, the piston rod/piston of cylinder **B** completes the positive stroke.

Phase 3: stroke **B –**
Line 5: upon reaching limit switch **b1**, the coil of relay **Z** energizes, by closing its contact **z1** it latches, contact **z** opens simultaneously on **Line 3**, interrupting the latching of the relay **Y** coil.
Contact **y1** of **Line 4** opens and interrupts the energizing of solenoid **B3**, permitting the return of the piston rod/piston of cylinder **B**.

Phase 4: stroke **C +**
Line 6: upon reaching limit switch **b0**, with contact **z2** closed in this phase, solenoid **B5** of the valve energizes, allowing the positive stroke of the piston rod/piston of cylinder **C**.

Phase 5: stroke **C –**
Line 7: upon reaching limit switch **c1**, the coil of relay **K** energizes, closing its contact **k1**, and latches, contact **k** on **Line 5** opens simultaneously and interrupts the latching of the relay **Z** coil.
Contact **z2** on **Line 6** opens and interrupts the energizing of solenoid **B5**, permitting the negative stroke of the piston rod/piston of cylinder **C**.

Phase 6: stroke **A –**
Line 8: upon reaching limit switch **c0**, with contact **k2** closed, the coil of relay **M** energizes, it closes contact **m1** and latches.
Line 9: at the same time contact **m2** closes, energizing solenoid **B2** of the valve, which by changing over allows the piston rod/piston of cylinder **A** to complete the negative stroke.

At the end of the negative stroke, in the **a0** position, the cycle resumes providing the **F.C.** button has not been pressed as contacts **x** and **x1** on **Lines 1** and **2** are closed. With the activation of limit switch **a0**, the relay **Y** coil is re-energized, its contact **y2** on **Line 8** opens, interrupting the latching of relay **M**, contact **m2** opens and solenoid **B2** on **Line 9** is no longer energized.
Conversely, by pressing the **F.C.** button, the latching of relay **X** is interrupted thereby removing the power supply to limit switch **a0**, the sequence will continue until it reaches the end of the cycle and then stop.

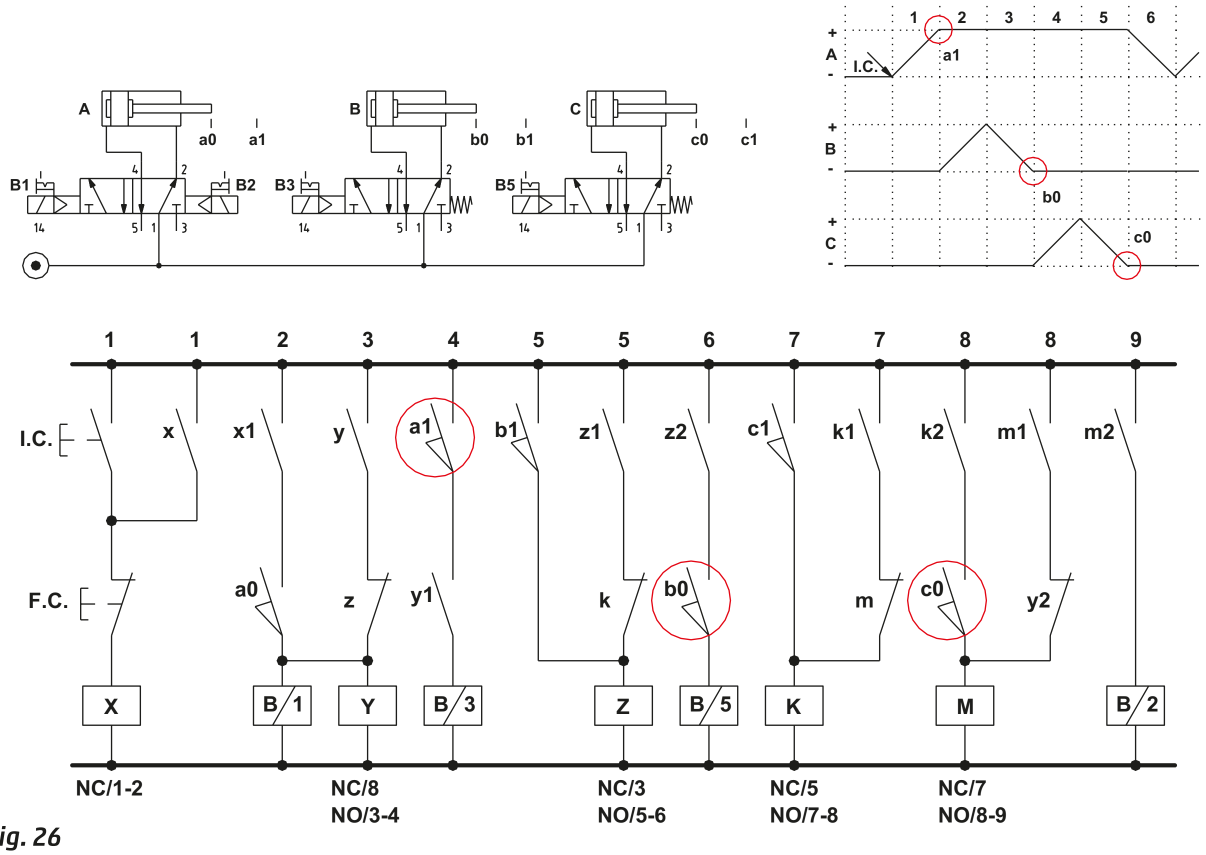


Fig. 26

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