



Learner Centric Advanced Manufacturing Platform



PNEUMATICS BASIC TRAINING

WP6 COLLABORATIVE LEARNING FACTORY



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EXECUTIVE SUMMARY

The main task of the pneumatics in modern technology is to convert the energy of compressed air into mechanical work, which enables fast, clean and cost-effective implementation of linear and rotational movements. In robotics and automation, it is indispensable especially in final execution elements, where it ensures the reliable operation of grippers, vacuum systems and fixation of workpieces. With the development of the electro- pneumatics, its functionality is upgraded with smart valves and sensors that enable connectivity to controllers and energy efficiency within the framework of Industry 4.0.



1. PNEUMATIC CONTROLS

As a technology, the pneumatics has long played an important role in the performance of mechanical work. In recent times, it has also been used to solve automation problems.

Technological developments in the field of materials, constructions and production experience have influenced the quality and variety of pneumatic components. This increased the possibility of using the pneumatics in automation technology (Table 1).

Table 1: Areas of application of the pneumatics

General technique	Specific areas	Machining technology
clamping of workpieces, feeding of workpieces, positioning of workpieces, orientation of workpieces, branching of material flow	packing, filling, dosing, closing, drive shaft, opening, closing doors, material transportation, turning, turning, sorting, raising and lowering, stamping, pressing	drilling, turning, milling, sawing, grinding, forming, testing

Table 2: Pneumatics features and benefits

Quantity	There is enough air practically everywhere in unlimited quantities.
Transport	Air can be easily transported through pipes over long distances.
Storage	Compressed air can be stored in pressure vessels and then used. The air stored in this way can also be transported.
Temperature	Compressed air is almost insensitive to temperature fluctuations. This feature ensures reliable operation even in extreme conditions.
Security	Compressed air cannot cause a fire and cannot explode.
Purity	Unooled exhaust air does not pollute the environment.
Construction	Working components are simple and inexpensive in terms of construction.
Velocity	Compressed air is a fast working medium. We can achieve high piston speeds (impact cylinder) and fast switching.
Overload safety	Pneumatic tools and working components can be put under the safety load to stop without being damaged.



Table 3: Pneumatics disadvantages

Preparation	We need to prepare the compressed air properly. Dust particles and moisture must be removed, otherwise the service life of the pneumatic components is greatly reduced.
Compressibility	With compressed air, it is not possible to ensure a uniform and constant piston speed (only under special conditions – brake cylinder).
Diligence	The energy of the compressed air can only be used economically up to a certain pressure. At a normally applied pressure of 600 to 700 kPa (6 - 7 bar), maximum forces of 20000 to 30000 N can be achieved.
Venting	When venting, the air makes a lot of noise. This problem can be eliminated by using silencers.
Price	Compressed air is a relatively expensive form of energy, which is compensated by a long service life, high automation ability and relatively inexpensive equipment.

1.1. PNEUMATICS BASES

Everything on Earth is exposed to ambient pressure, or atmospheric pressure. Atmospheric pressure is characterized by changing with geographical location and weather. Atmospheric pressure is measured at an altitude of 0 meters and amounts to 101.325kPa or 1.01323 bar, i.e. approx. 1 bar.

$$tlak = p = \frac{silá}{površina} = \frac{F}{A}; \left[\frac{N}{m^2} \right]$$

$$1 Pa = \frac{1 N}{m^2} = 10^{-5} bar$$

$$1 bar = \frac{10^5 N}{m^2}$$

Absolute pressure is obtained by adding the pressure that occurs above atmospheric pressure, it is called overpressure, and the pressure that occurs under atmospheric pressure, we call it underpressure. Individual types of pressures are shown in Figure 1.



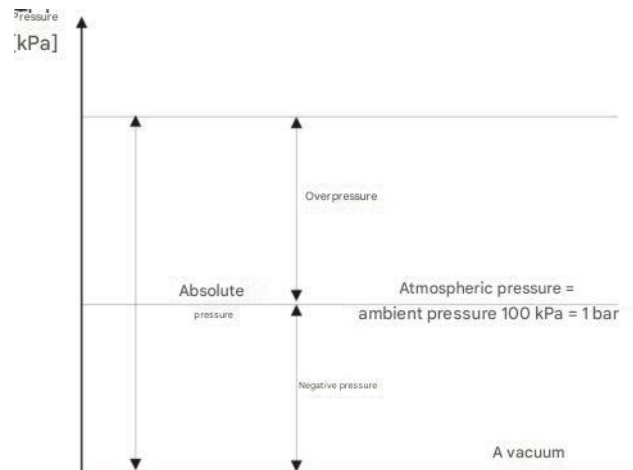


Figure 1: Types of pressures
 Source: Adapted from: Croser and Ebel, 1994

Air is characterized by the fact that it does not have a specific shape and can be compressed or expanded, while compressed air tends to expand or expand. Air compression is explained by Boyle Marriott's law, which states that volumes of equal quantities of a gas at a constant temperature are inversely proportional to absolute pressure, as shown in Figure 2. That is, the product of absolute pressure and volume at a constant temperature is constant.

$$p_1 \cdot V_1 = p_2 \cdot V_2 = p_3 \cdot V_3 = konst$$

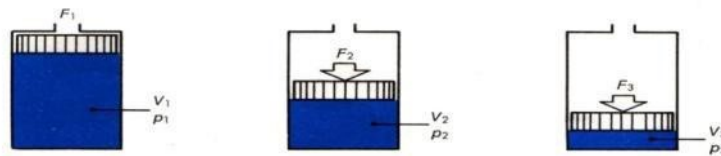


Figure 2: The Principle of Boyle's Marriott's Law
 Source: Croser and Ebel, 1994

If the air is heated at constant pressure, as shown in Figure 3, its volume will increase with each degree by 1/273 of the volume it would have at 0°C and the same pressure. However, when cooling, the volume will decrease by the same value.

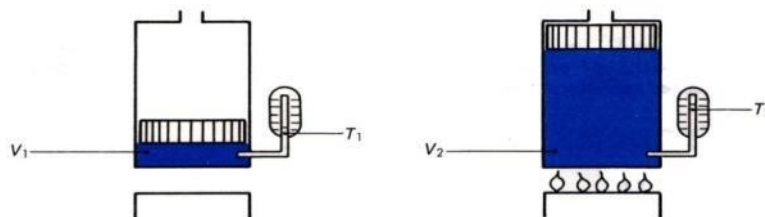


Figure 3: The Principle of Gay Lussac's Law
 Source: Croser and Ebel, 1994



This is proved by Gay Lussac's law, which states that at the same pressure, volumes of equal amounts of gas are proportional to absolute temperatures.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

V1 = volume at temperature T1; V2
= volume at temperature T2

From the Basic Law we can derive:

$$V_2 = V_1 \frac{T_2}{T_1}$$

Here, the change in volume is:

$$\Delta V = V_2 - V_1$$

$$\Delta V = V_1 \frac{T_2}{T_1} - V_1$$

$$\Delta V = V_1 \frac{(T_2 - T_1)}{T_1}$$

For V2, however, the following applies:

$$V_2 = V_1 + \Delta V$$

$$V_2 = V_1 + \frac{V_1}{T_1}(T_2 - T_1)$$

The temperature must be given in degrees Kelvin [K]. T[K] = °C + 273.

If we combine the Boyle-Mariott and Gay-Lussac laws, we get a general gas equation for enclosed gases.

$$\frac{p \cdot V}{T} = konst \quad \text{oz.} \quad \frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

SUMMARY

The atmosphere that surrounds the Earth presses on us with its weight and creates pressure in the environment that acts evenly in all directions. Atmospheric pressure varies depending on altitude and weather.



QUESTIONS AND TASKS

1. Explain what happens to a plastic bottle that is filled with air (ambient pressure) in the hills and then returned to the valley with it.
2. Explain what happens to an empty plastic bottle that we open high up in the hills.
3. In a vessel with a volume of $V_1 = 1 \text{ m}^3$, the air at pressure $p_1 = 100 \text{ kPa}$. The air is compressed with a force F_2 to a volume of $V_2 = 0,5 \text{ m}^3$ at the same temperature. Calculate the pressure p_2 .
4. Heat 0.8 m^3 of air at a temperature of $T_1 = 293 \text{ K}$ (20°C) to a temperature of $T_2 =$
5. 344 K (71°C). Find out how much the volume of air increases?



1.2. OBTAINING COMPRESSED AIR

To obtain compressed air, we need compressors that push the air to the desired pressure. The air is prepared centrally and then guided through pipelines to the individual devices.

When planning compressor capacities, we must anticipate at least a 10% increase in compressed air consumption due to the subsequent connection of new pneumatic devices.

Depending on the working pressure and the required amount of compressed air, different types of compressors are used. Basically, we distinguish between compressed air production on the principle of volume reduction and on the principle of acceleration.

In the first principle, we reduce the volume of the room in which the air is enclosed. Piston compressors (rotary and straight-line) work on this principle. The second principle is to obtain compressed air based on mass acceleration, where the air flow increases in speed. On this basis, turbo compressors work.

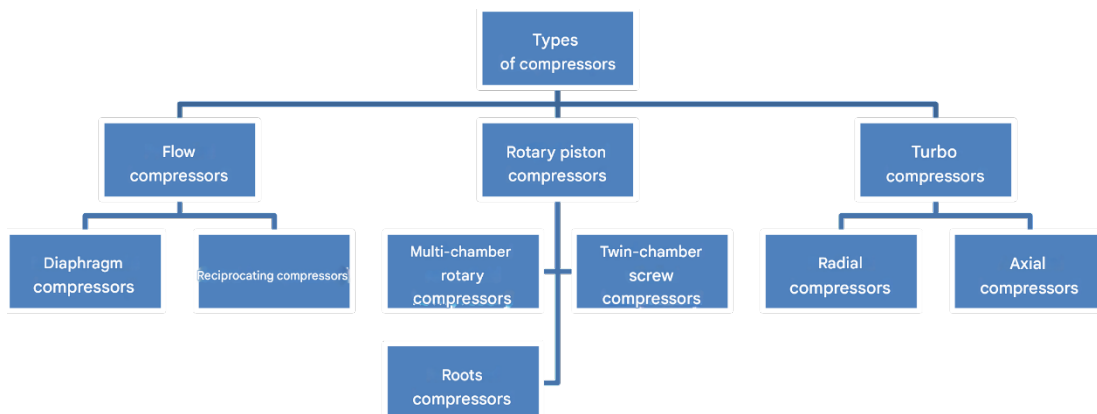


Figure 4: Types of compressors
Source: Croser and Ebel, 1994

1.2.1. IN-LINE RECIPROCATING COMPRESSORS

Reciprocating compressors are mostly used in practice, as they are suitable for low, medium and high pressures. Their working range ranges from approx. 100 kPa and up to several thousand kPa. Air is sucked in through the inlet valve and pushed through the outlet valve into the pressure line. The principle of operation of the piston compressor is illustrated by Figure 5.



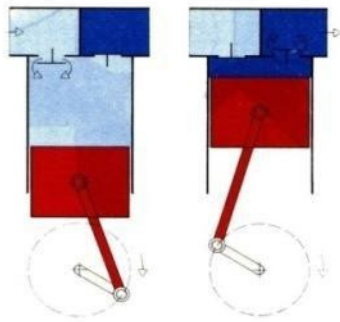


Figure 5: Piston compressor
Source: Croser and Ebel, 1994

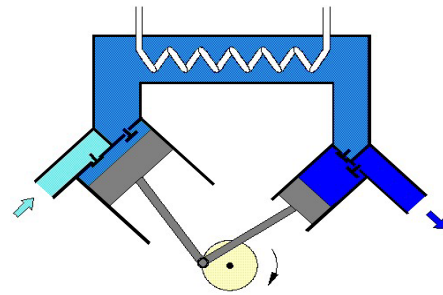


Figure 6: Two-stage compressor with intermediate cooling
Source: Croser and Ebel, 1994

Optimal pressure ranges for reciprocating compressors:

up to 400 kPa (4 bar)	One-step
up to 1500 kPa (15 bar)	Two-step
over 1500 kPa (15 bar)	three- or multi-stage

Possible, but uneconomical production of compressed air:

up to 1200 kPa (12 bar)	One-step
up to 3000 kPa (30 bar)	Two-step
above 22000 kPa (220 bar)	three- or multi-stage

1.2.2. ROTARY PISTON COMPRESSORS

To produce higher pressures, we use multistage compressors. Between individual stages, the air is cooled. With rotary piston compressors, the air is compressed by rotating pistons. When compressed, the compression space is continuously reduced. An example of a two-stage reciprocating compressor with intermediate cooling is shown in Figure 5.

1.2.3. DIAPHRAGM COMPRESSORS

Diaphragm compressors belong to the group of piston compressors. An example of a piston compressor is shown in Figure 6, where the compression space is separated from the piston by a diaphragm and air cannot come into contact with the sliding surfaces of the piston, taking on compressor oil and unpleasant odors. For this reason, membrane compressors are used in the food, chemical, pharmaceutical industries, and dentistry.



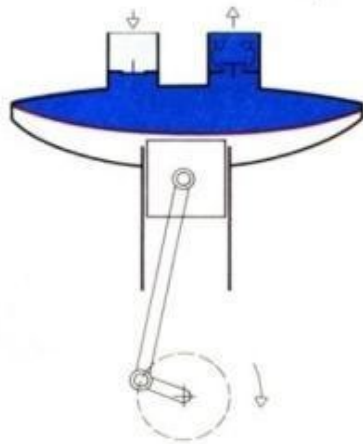


Figure 7: Diaphragm compressor
Source: Croser and Ebel, 1994

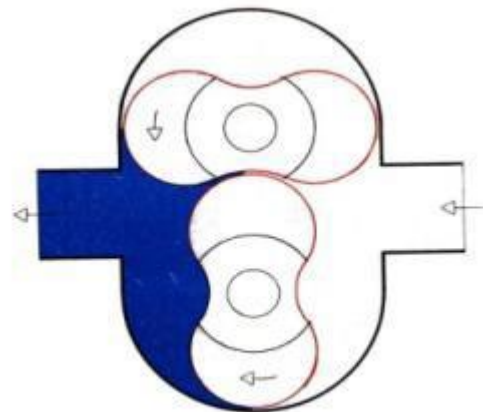


Figure 8: Lobe compressor
Source: Croser and Ebel, 1994

1.2.4. ROOTS COMPRESSOR

Air is transported from one side to the other without changing its volume. Pressure is created when air is forced out of the compressor. The principle of operation of the Roots compressor is shown in Figure 8.

1.2.5. SCREW COMPRESSORS

The screw-shaped profile is gripped by two shafts (runners), as shown in Figure 9. When rotating, the air captured in the profile is compressed into the pressure line.

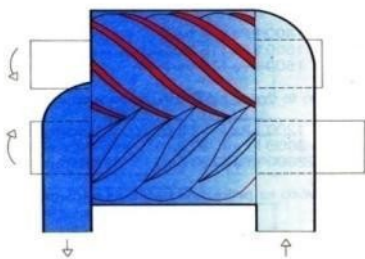


Figure 9: Screw Compressor
Source: Croser and Ebel, 1994

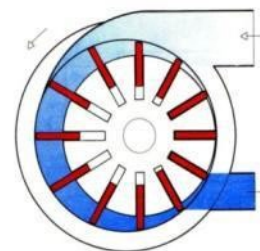


Figure 10: Multi-chamber rotary compressor
Source: Croser and Ebel, 1994

1.2.6. MULTI-CHAMBER ROTARY COMPRESSOR

The classic piston is replaced by rotating fins, which are inserted into the rears of the eccentrically inserting rotor. Figure 10 shows how the racks form individual chambers, the size of which varies as they rotate. Compressors are distinguished by smooth running, create compressed air very evenly and without shocks.



1.2.7. TURBO COMPRESSORS

They work on the principle of air acceleration. They are distinguished by a very large capacity. One or more turbine wheels cause an air flow, the energy of motion or kinetic energy is then converted into pressure or potential energy. If the air is accelerated in the axial direction, we are talking about the axial compressor shown in Figure 11. However, if the air is accelerated in the radial direction, we are talking about the radial compressor shown in Figure 12.

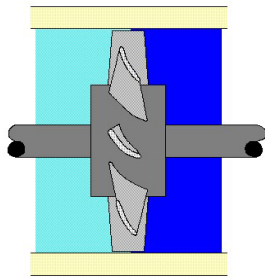


Figure 11: Axial Compressor
Source: Croser and Ebel, 1994

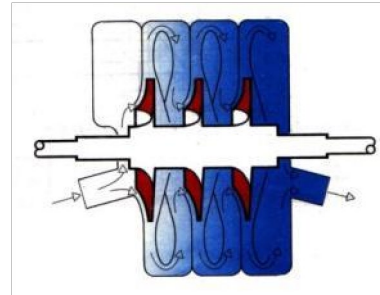


Figure 12: Radial compressor
Source: Croser and Ebel, 1994

SUMMARY

When choosing the right compressor, we can use the criteria presented in Table 4.

Table 4: Compressor selection criteria

Capacity	The amount of air emitted by the compressor. We distinguish between theoretical and effective performance. The product of the moving volume and the number of revolutions represents the theoretical performance. Effective capacity is the amount of air we have available.
Pressure	We distinguish between operating pressure (compressor pressure, in the storage tank, pipelines, to consumers) and working pressure (required at a particular workplace).
Drive	In industry, we use drive with electric motors, and internal combustion engines on construction sites or in the field.
Regulation	By means of regulation, we adjust the operation of the compressor to uneven air consumption.
Cooling	Depending on the amount of heat generated during air compression, air cooling is distinguished, which is used in lower power compressors. Cooling is carried out with the help of cooling fins. In the case of higher power compressors, however, air cooling is not sufficient and we use water or a combination of air and water cooling.



QUESTIONS AND TASKS

1. Explain a practical example of the use of a single-stage and multi-stage reciprocating compressor.
2. What is the essential difference between a reciprocating compressor and a rotary screw compressor?
3. The compressor sucks in 1850 litres of air at an ambient pressure of 100 kPa and compresses it into a 150-litre storage tank. How much pressure is there in the container if the temperature does not change?



1.3. AIR PREPARATION

The air that we want to use in a pneumatics must have some specific properties, as it must not contain moisture, dust, dust and other particles.

The air sucked in by the compressor always contains a certain portion of water in the form of water vapour, which is given by the % relative humidity of the air. The relative humidity of the air depends on the temperature and pressure of the surrounding area. The higher the temperature, the more moisture can be in the air. The air is saturated with moisture at 100% relative humidity, then condensate begins to be secreted on the walls, as the walls of the compressor are colder.

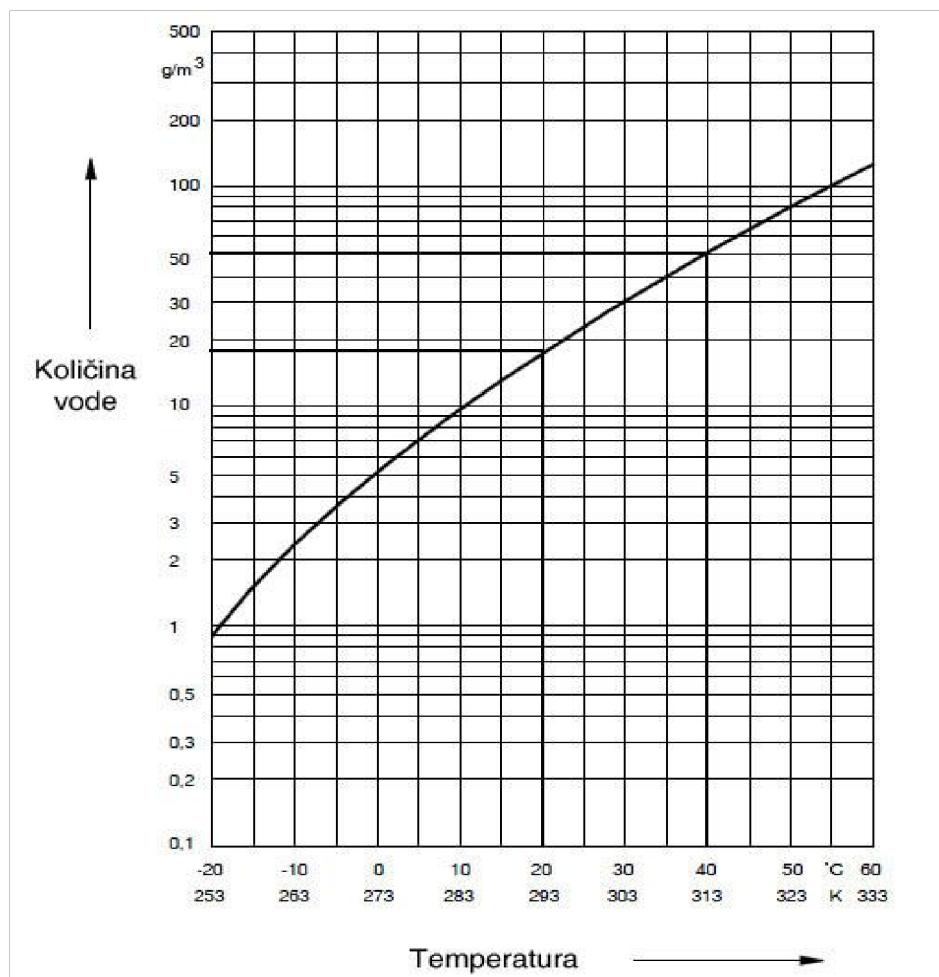


Figure 13: Saturation curve
Source: Croser and Ebel, 1994

Absolute humidity is the amount of water contained in 1 m³ of air. The amount of saturation or maximum humidity is the amount of water that 1 m³ of air can accept at a certain temperature. The amount of saturation at a given temperature can be read in Figure 13.



$$\text{relativna vlažnost} = \frac{\text{absolutna vlažnost}}{\text{količina nasičenja}} * 100 \%$$

If the condensate is not drained, it gets into the pneumatic system, which has harmful consequences, which manifest themselves as corrosion in pipes, valves, cylinders and other devices, as well as as lubricant leaching in moving parts. As a result, the functions of the components and the service life of the system are severely disrupted.

Too much moisture in the compressed air shortens the life of the pneumatic system. For this reason, we need to use an air dryer to reduce the amount of moisture to the desired value. For air drying, we can choose between absorption and adsorption drying and cooling drying.

Reduced maintenance costs, shorter downtimes and increased system reliability ensure a relatively fast amortization of the air dryer.

1.3.1. ABSORPTION DRYING

Absorption drying is the chemical process shown in Figure 14. Due to the high operating costs, this method is used less often.

A pre-filter removes larger water and oil droplets from the air. When flowing into the dryer, the compressed air is swirled, then flows through the drying chamber, which is filled with desiccant. The desiccant is represented by 100% silica in the form of grains. The chemical agent that reacts with moisture is dissolved and collected in the lower, collecting part of the dryer. The solution must be drained regularly and a new desiccant added.

1.3.2. DESICCANT DRYING

It is the property of a solid material to retain moisture on its surface. The drying material, also called gel, is a granulate predominantly made of silica. By adsorption, the lowest dew point (up to -70oC) can be achieved. Always use two adsorbents. When the gel in the first adsorbent is saturated with moisture, drying is switched to the second, and the first is regenerated with hot air. The principle of operation is shown in Figure 15.



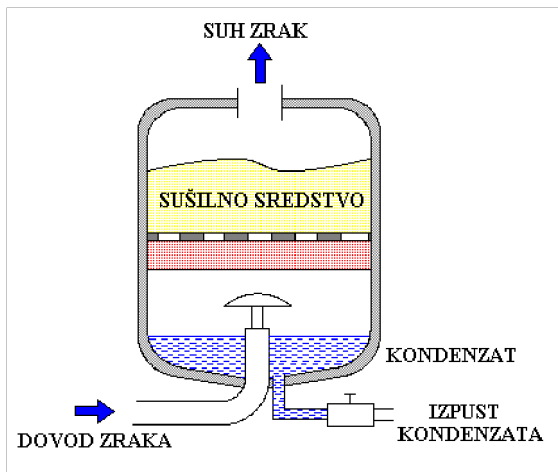


Figure 14: Absorption drying
Source: Croser and Ebel, 1994

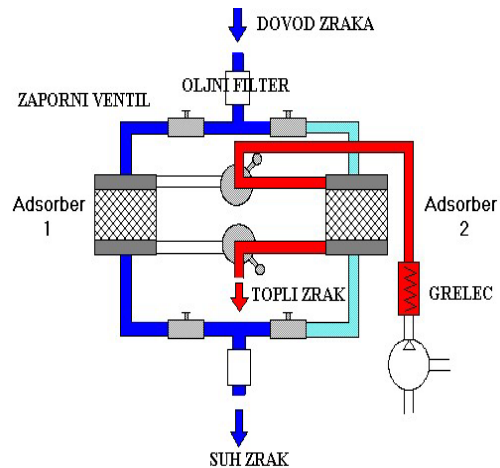


Figure 15: Absorption drying
Source: Croser and Ebel, 1994

1.3.3. DRYING BY COOLING

Most often, in practice, the drying of compressed air by cooling, represented by Figure 16, is used. Air flowing through an air heat exchanger – air where its temperature drops slightly and consequently excretes some of the moisture. The air then flows into the refrigerating chamber, cools below the dew point. Condensed moisture is collected in a laxative vessel.

Dry air is transported through an air-to-air heat exchanger, where it is heated with the help of air flowing into the heat exchanger, thus saving a little on energy consumption.

The dew point temperature is the temperature to which the air needs to be cooled in order for the moisture to condense. The greater the temperature difference to the dew point, the more moisture condenses. When drying air by cooling, dew points between 20°C and 50°C can be reached.

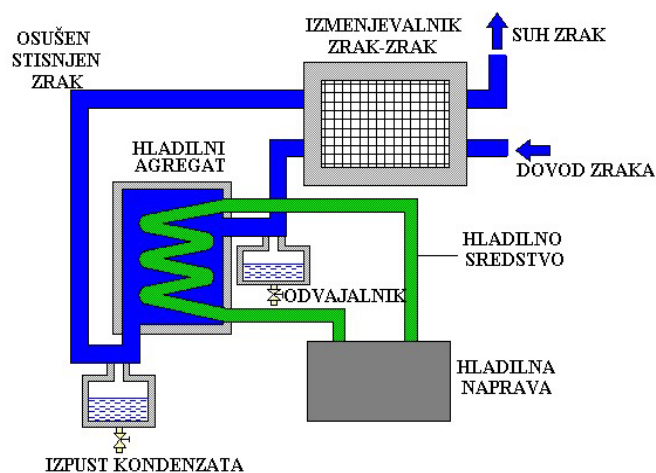


Figure 16: Cool-down drying
Source: Croser and Ebel, 1994



1.3.4. COMPRESSED AIR NETWORK

In order to distribute compressed air to different consumers reliably and smoothly, a whole range of conditions must be taken into account. The correct dimensioning of the pipe network is just as important as the pipe material used, flow resistances, network design and maintenance.

When planning a new network, we must always provide for a certain reserve for as yet unknown new consumers. Therefore, the main line should be of a larger diameter than is required in the current situation, a place should be provided in the compressor station for the installation of an additional compressor, air dryer, collection tank. Depending on the available working spaces and possible development plans, we can provide in the main line branches and valves for the subsequent extension of the network.

A pressure drop occurs in all pipes due to flow losses, especially where the pipeline is narrowed, diverted, at branches and pipe connections. These losses must be taken into account when dimensioning the compressor. There should be no pressure drop of not more than 10 kPa or 0,1 bar throughout the network.

A modern compressed air distribution system requires a special quality pipe material.

It must allow:

- Low pressure losses
- Tightness
- rust resistance and
- the possibility of extending the pipeline.

In addition to the price of the material, we must also take into account the cost of installing the distribution network, which is the lowest when using plastic pipes. Pipes made of artificial material are soldered 100% tightly by gluing, in addition, extending the mesh is very easy and inexpensive.

Copper and steel pipes have a low purchase price, but they need to be soldered by jointing, welding or threading. If the joints are not carried out carefully, thread clippings, welding residues, sealing material may remain in the pipes, which later causes big problems. Installing such a network is expensive. For small and medium diameters of the pipeline, pipes made of artificial substance are more advantageous, only the purchase price is higher than that of other materials.

Due to pressure fluctuations in the network, the pipes must be reliably hardened so that they do not fluctuate (vibrate) with pressure changes. Due to the vibration of the pipe, leaks occur in twisted, threaded or welded places.



In addition to the correct dimensioning and the appropriate quality of the material used, the implementation of the distribution network is also very important for economical operation. The compressor supplies the system with compressed air at specified time intervals. It often happens that air consumption only increases for a short time, which leads to a decrease in pressure in the network. For such cases, it is recommended to design the main line in the form of a ring, which allows for better supply of compressed air (annular line instead of open line). An example of an annular network is illustrated in Figure 17.



Figure 17: Ring water
Source: Croser and Ebel, 1994

In order not to disturb the pneumatic compressed air supply during maintenance, repairs or extensions, the mesh should be made in a lattice or divided into individual sectors. T-cut outlets and plug-in coupling collectors can be provided. Shut-off valves or standard ball valves may be provided on branches. An example of the implementation of a lattice network is shown in Figure 18.

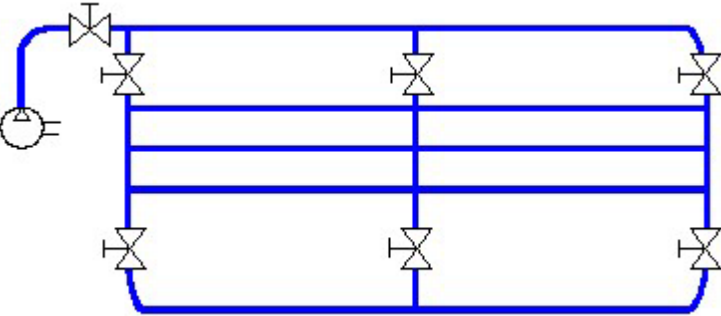


Figure 18: Lattice Mesh
Source: Croser and Ebel, 1994

Despite the good central expulsion of condensate from the compressed air, condensate can also be ejected in the pipe system due to pressure reduction or low outside temperatures. Due to the collection and drainage of this condensate, the main lines should be laid with a 1–2% slope in the direction of the air flow. They can be laid in steps. Condensation crucibles are provided at the lowest points for the collection and periodic drainage of condensate. An example of this network implementation is shown in Figure 19.



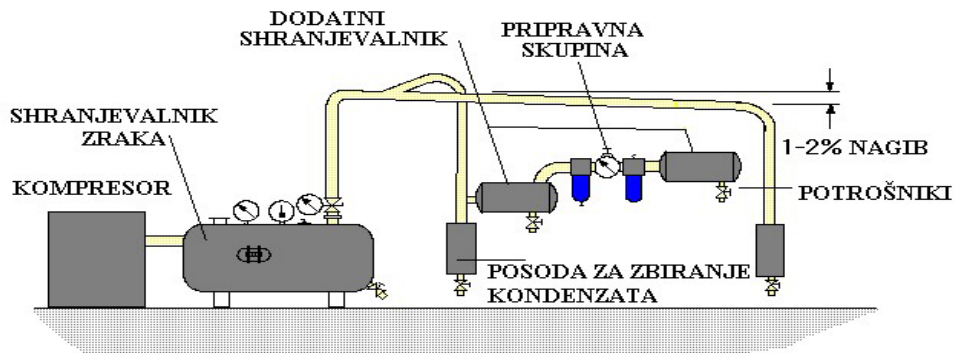


Figure 19: Compressed air supply system
Source: Croser and Ebel, 1994

The increase in the cost of compressed air preparation is also influenced by the tightness of the devices and the network itself, since even a small leak means significant amounts of lost air. Due to leaks, leaking air can also have a detrimental effect on the processing material (e.g. food in the food industry). The amount of air loss due to leakage can be read in Figure 20.

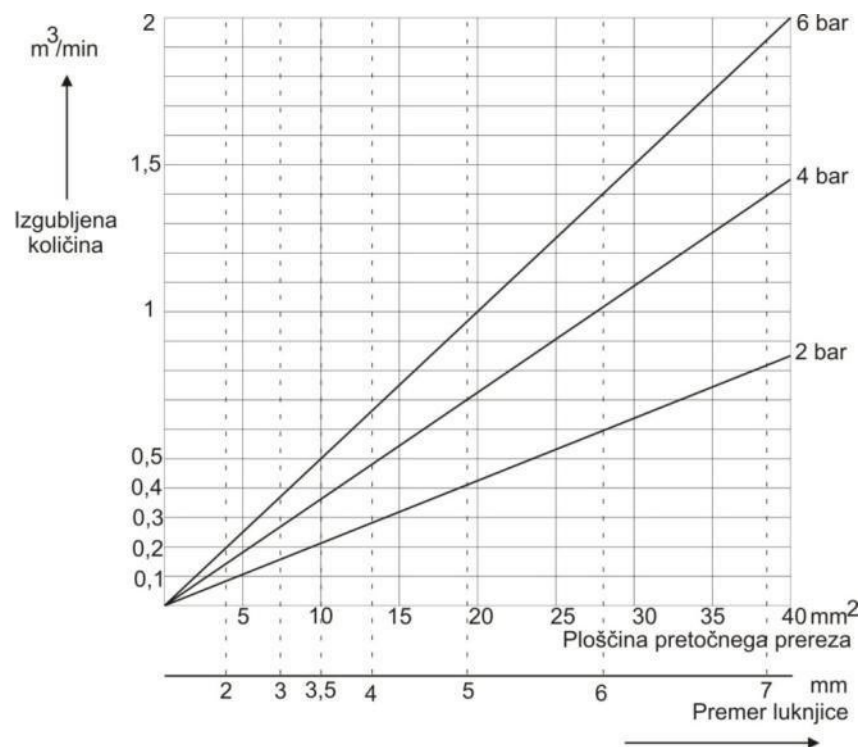


Figure 20: Diagram of air loss due to leakage
Source: Croser and Ebel, 1994

1.3.5. SIZING OF PIPELINES

The diameter of the pipeline must be dimensioned in such a way that the pressure drop from the collector to the consumer is not more than 10 kPa (0.1 bar). A higher loss would



compromise economy and reduce the capability of pneumatic devices. When planning, we must also take into account the subsequent increase in compressor capacity due to the increased demand for compressed air.

When determining the diameter of the pipe, we must consider:

- Flow
- Length
- Allowable pressure drop
- Operating pressure
- the type and number of damping points.

To determine the diameter of the pipe, we need to know the pneumatic length of the pipeline. For pipe connections, branches, arcs, for shut-off valves, resistors with the alternate length of the pipeline are determined. The choice of the inner diameter of the pipe also depends on the operating pressure and flow rate. It is best to determine the diameter of the pipe using the nomogram shown in Figure 21.

On the nomogram, connect the point on line A (line length) with the point on line B (flow rate) and extend the line to C (axis 1). Connect the point on the line E (operating pressure) with the point on the line G (pressure drop) and obtain the intersection with the line F (axis 2). Connect the intersection of axis 1 and axis 2. On line D (clear diameter of the pipe), the theoretical diameter of the pipe is obtained at the point of intersection.



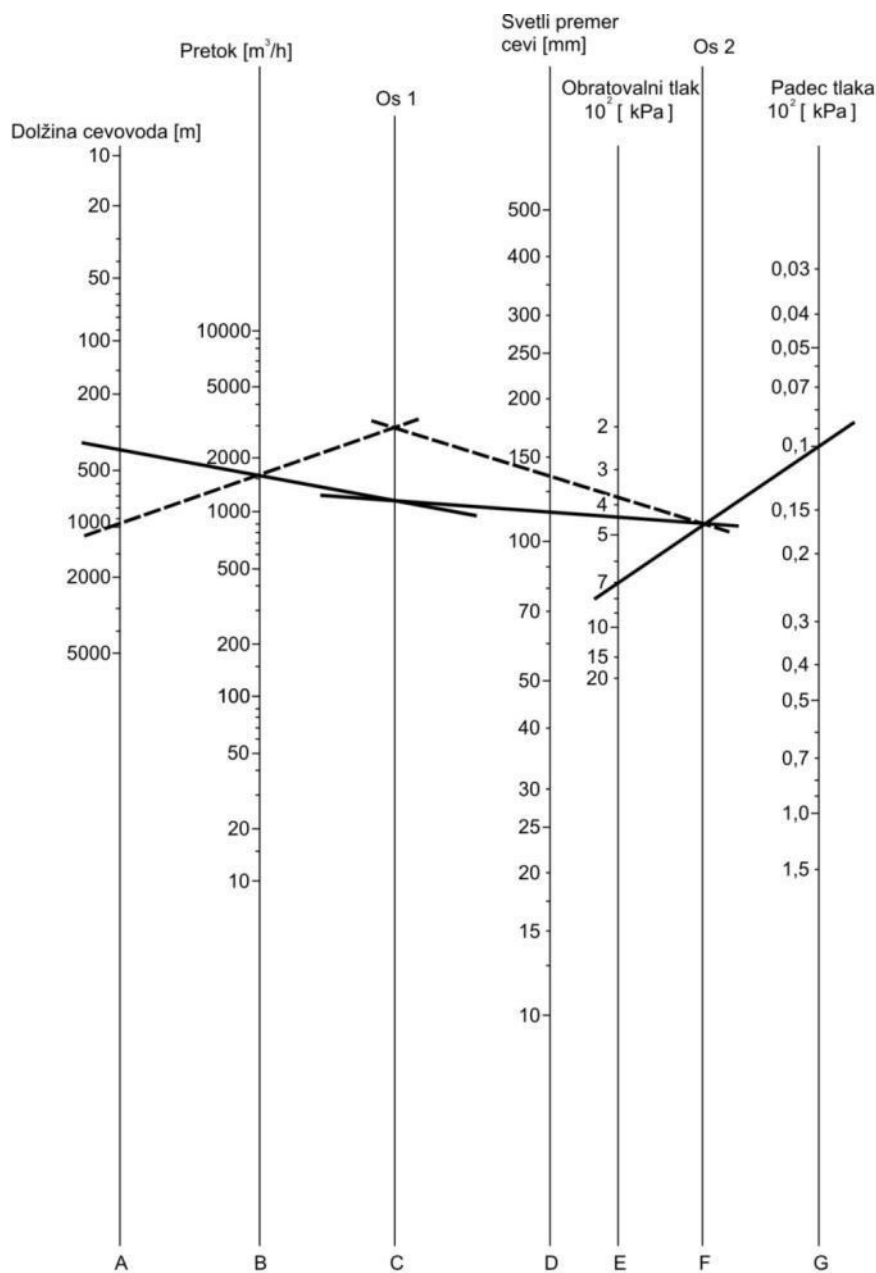


Figure 21: Nomogram to determine the clear diameter of the pipe
 Source: Croser and Ebel, 1994

1.3.6. FLOW RESISTANCE

Any air flow inside the pipe is disrupted by flow resistances that cause a constant drop in pressure inside the pipe system. Pressure drop is also caused by pipe connections, branch fittings, arcs and other necessary fittings. Pressure losses in the pipeline cannot be prevented, but they can be significantly reduced by using appropriate materials and proper installation.



Flow resistances are given by the alternate length of the pipe. By alternate length we understand straight pipes with the same flow resistance as the damping element. The diameter of the alternate length is equal to the diameter of the pipe line. The alternate length of the tubes is read for the individual damping elements on the basis of a known diameter using the nomogram in Figure 22.

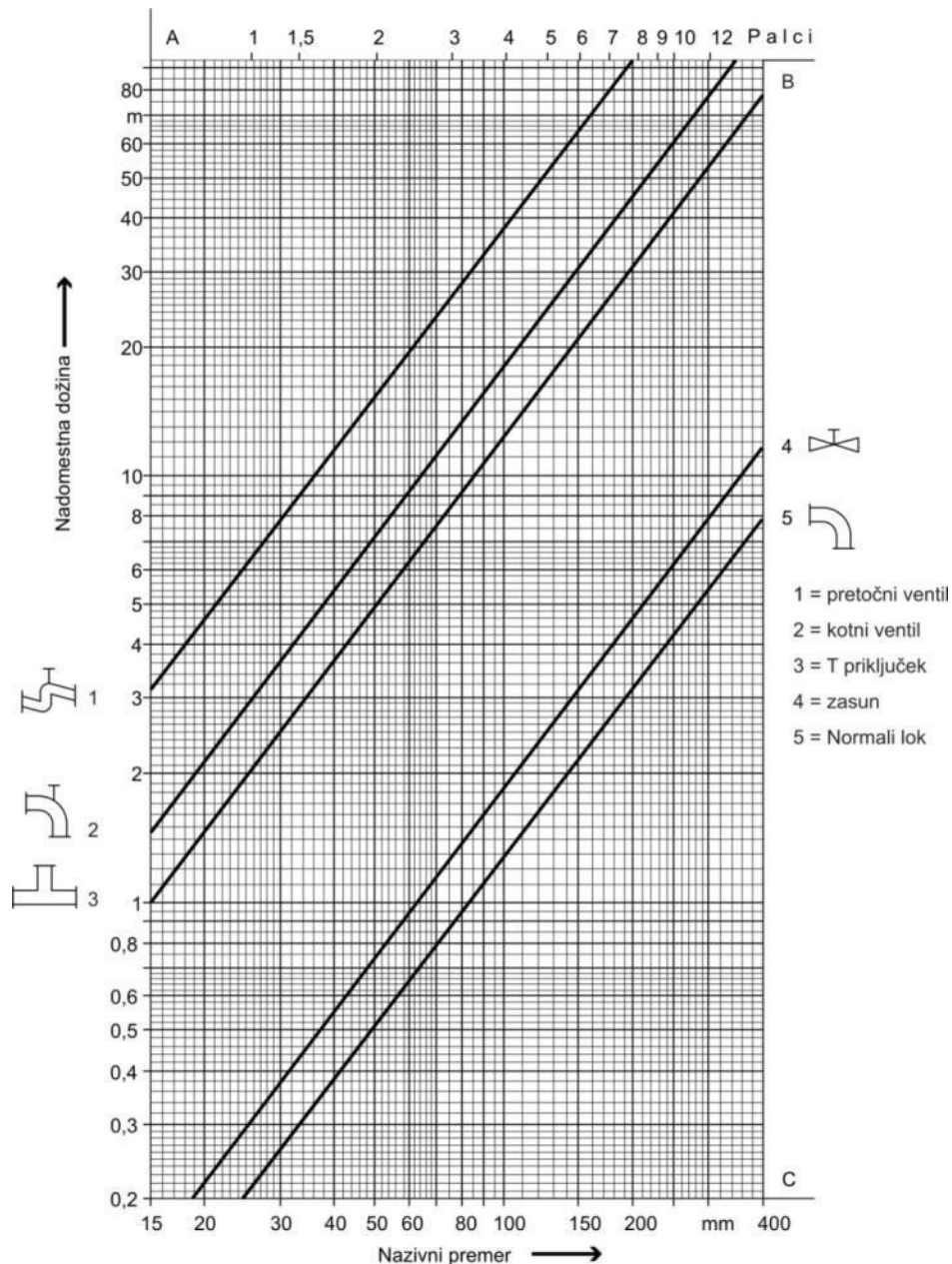


Figure 22: Nomogram for determining the alternate length of the pipe
Source: Croser and Ebel, 1994

1.3.7. COMPRESSED AIR STORAGE

The storage tank ensures the stability of the compressed air supply, compensates for pressure fluctuations in the network due to withdrawal. Due to the large area of the storage tank, the air



is cooled, eliminating part of the moisture in the form of condensate. The components of the storage are shown in Figure 23.

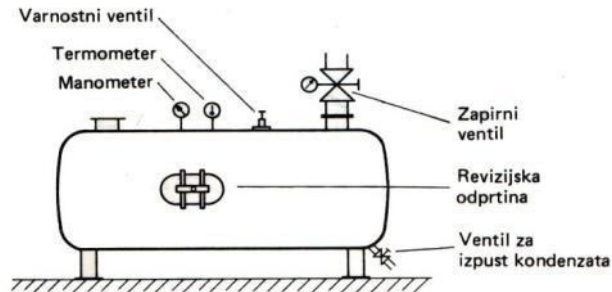


Figure 23: Air Storage
Source: Croser and Ebel, 1994

The size of the saver is conditioned by:

- compressor capabilities
- Air consumption
- networks, if we have built-in additional storage
- type of regulation, and
- permissible pressure difference.

EXAMPLE

Use the diagram in Figure 24 to determine the size of the storage next to the data:

Compressor capabilities	$\dot{V} = 20 \text{ m}^3 / \text{min}$
Number of switch-ons/hour	$z = 20$
Pressure difference	$\Delta p = 100 \text{ kPa}$
Storage Size	$V_B = ?$



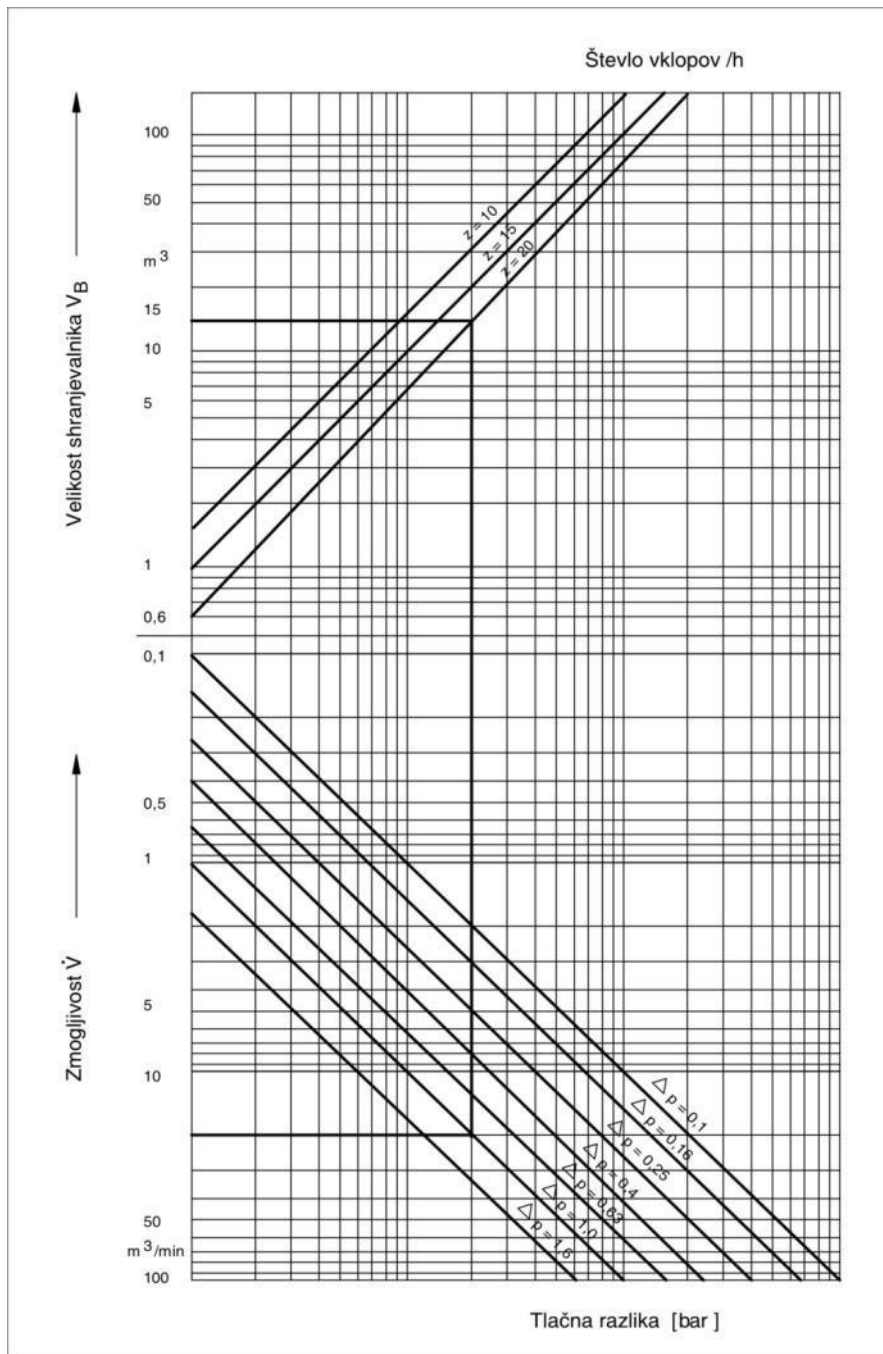


Figure 24: Diagram for determining the size of the store by stopping
Source: Croser and Ebel, 1994

1.3.8. PREPARATORY GROUP

The preparation group is designed to prepare compressed air. The preparation group consists of an air filter, a pressure regulator, a pressure gauge and an oiler. The composition of the preparatory group is illustrated by Figure 25 and in cross-section by Figure 26.

We use it in every pneumatic control system. In general, compressed air should not be oiled unless necessary by means of moving parts in valves and cylinders. Where special lubrication is required, a sufficient amount of oil must be constantly added to the air.



Oiling of compressed air should only be provided for parts of the system that require oiled air. The oil that gets into the compressed air in the compressor is not suitable for lubricating pneumatic components, so it is necessary to remove it with a device for removing (extracting) burnt oil.

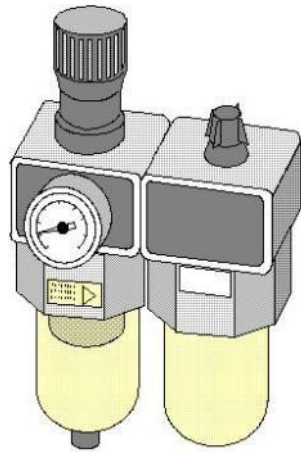


Figure 25: Preparatory Group
Source: Croser and Ebel, 1994

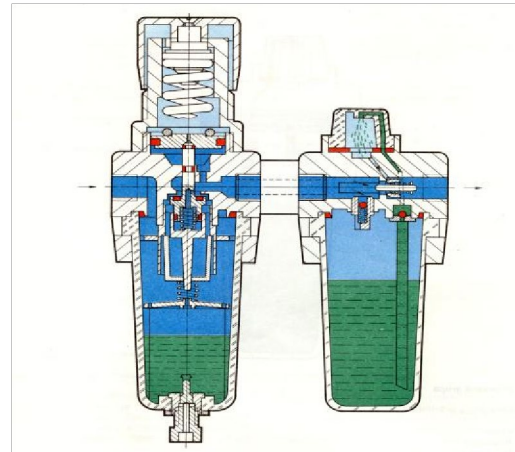


Figure 26: Preparatory Group
Source: Croser and Ebel, 1994

Cylinders with temperature-resistant seals should not be supplied with oiled air, because the oil washes out the special grease with which the cylinder is lubricated at the manufacturer.

If you want to use unoiled air in a system that has operated with oiled air, you need to relubricate the valves and cylinders because the original grease has been washed out.

Oiling of compressed air should be provided in cases of:

- Extremely fast movements
- large diameter cylinders (oiler only for such cylinders).

Over-oiling can cause:

- Functional disorders in the components
- increased environmental burden
- hardening of components after prolonged dormancy (sticking of seals).

In the preparation group, we must take into account:

- The size of the preparation group is determined depending on the air consumption (m³/h).
- An excessive increase in air consumption leads to a sharp drop in operating pressure. We have to take into account the factory data.
- The operating pressure must not be higher than the specified value. The ambient temperature should not be higher than 50°C (due to the plastic glass).



Table 5: Elements of preventive maintenance of the preparatory group

Component	Task type
Compressed air filter	Through a transparent glass, it is necessary to regularly control the level of condensate, which should not exceed the maximum level. If the level is too high, the air carries the condensate forward. Drain the accumulated condensate using a drain valve at the bottom of the glass. At the same time, we control the contamination of the filter cartridge and, if necessary, replace it with a new or cleaned one.
Compressed air pressure regulator	No maintenance required. However, it is a condition that a filter is installed in front of it.
Compressed air oiler	Regularly check the oil level and top it up if necessary. Top up can be done during operation. Before and during filming, the glass is vented using an additional manual valve. Only mineral oils should be used. The jar must not be cleaned with trichloroethylene or a similar agent.

Condensate, impurities and too much oil can cause wear and tear on the moving parts and seals of pneumatic components. Due to leaks, harmful substances can also come out of the system and contaminate processing products, e.g. in the food, pharmaceutical and chemical industries, to such an extent that they are unusable.

The choice of compressed air filter is very important when supplying the pneumatic system with quality compressed air. The size of the filter is determined by the pore size. The size is given by the minimum particle size that the filter can still hold.

With the appropriate design, compressed air filters are also useful for filtering condensate. The accumulated condensate must be drained before it reaches the upper level, otherwise it is carried forward by the air stream through the filter. The air flow through the filter and the composition of the filter are shown in Figure 27.

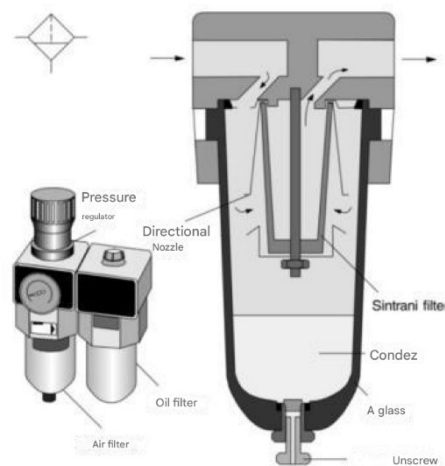


Figure 27: Fine filter
Source: Croser and Ebel, 1994

If the air is not dried, too much condensate quickly accumulates in the glass or has to be drained very often. In such a case, it is recommended to use an automatic laxative device instead of a manual valve. The automatic drainage device consists of a float which, when the condensate rises to the maximum level, causes the drain valve to open. When the condensate level is reduced to a minimum level, the valve closes again. Additionally, manual draining is also possible - performance testing.

Air flows into the filter through the directional blades, which swirl it. Due to centrifugal force, larger water droplets and solid particles fly against the wall of the glass and slide towards the bottom. The air purified in this way flows through the filter cartridge. The filter cartridge retains any solid particles larger than the pore size. With normal filters, we can choose between 5 μm and 40 μm cartridges.

By the filtration rate, as a characteristic of the filter, we understand the percentage amount of particles that the filter excretes from the total amount from the compressed air. With a filter size of 5 μm , as a rule, a filtration rate of 99.99% can be achieved.

After prolonged operation, the filter cartridge must be replaced because many pores can already be clogged. Although the filter still has its function, the airflow is severely obstructed and thus the pressure drop increases.

When the filter cartridge should be replaced can be determined by its appearance (dirt) or by measuring the pressure difference between the pressure of the filter inlet and outlet. Replace the filter element at a pressure difference of 40 to 60 kPa (0.4 to 0.6 bar). For such control, it is recommended to install a differential pressure gauge.

The period for replacing the filter cartridge depends on the quality and consumption of compressed air, as well as on the pore size of the cartridge. Filter maintenance includes replacing or cleaning the filter cartridge and draining the condensate.

When cleaning, we must follow the manufacturer's instructions regarding cleaning products. It is usually sufficient to wash the filter cartridge in warm soapy water and blow it out with air in the opposite direction.

1.3.9. PRESSURE REGULATOR

The very production of compressed air causes pressure fluctuations. Pressure fluctuations in the manifold network are then influenced by the inclusion of valves, cylinder speeds, throttle valves.



For reliable operation of the pneumatic system, a constant level of pressure is required, which is provided by a pressure regulating valve - pressure regulator. The pressure regulator is installed at the connection of the pneumatic system to the compressed air distribution network. It ensures a constant supply pressure of the pneumatic system (secondary pressure) independently of pressure fluctuations in the network (primary pressure). The pressure regulator is included in the preparation group behind the filter. The secondary pressure level can be adjusted depending on the requirements of the supplied system.

With higher operating pressure, the energy utilization of compressed air worsens and the utilization increases. With a lower operating pressure, the ability to work decreases.

The inlet (primary) pressure must always be greater than the outlet (secondary) pressure. Pressure regulation is carried out automatically by the diaphragm. The outlet pressure acts on the diaphragm from the upper side, and from the lower side acts the spring. The spring tension is adjustable with a hand screw.

If the pressure on the secondary side increases, e.g. When the load on the cylinder changes, the diaphragm is pushed down towards the spring. The flow valve closes or closes. The diaphragm valve opens and the increased pressure is released through the vents to the open air (safety valve function). The principle of operation of the pressure regulator with venting is shown in Figure 28.

If the pressure on the secondary side drops, the spring raises the diaphragm and opens the flow valve. Regulating the air pressure to the set operating pressure means constantly opening and closing the flow valve. The built-in pressure gauge shows the operating (secondary) pressure.

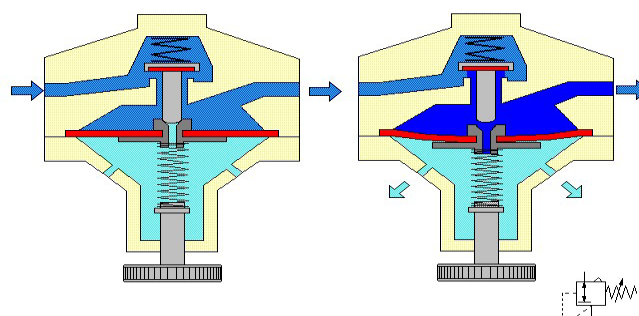


Figure 28: Pressure regulator with venting
Source: Croser and Ebel, 1994

In the case of a pressure regulator without a vent, when the operating (secondary) pressure increases, the diaphragm is pressed down against the spring. This closes or closes the flow valve. The flow valve can only be reopened when the operating pressure is less than the primary pressure or less than that set by the spring.

1.3.10. OILER

The oiler allows you to protect the elements from corrosion and wear of moving parts. The oiler works according to the Venturi principle, which is illustrated in Figure 29. The pressure



difference Δp between the pressure at the beginning of the nozzle and the pressure at the narrowed point of the nozzle is used to suck the liquid out of the glass and to disperse it into the compressed air.

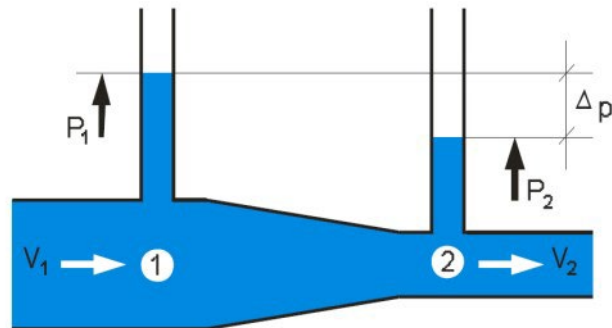


Figure 29: The Venturi Principle.
Source: Croser and Ebel, 1994

The compressed air flowing through the oiler causes a vacuum in the narrowed part. By means of a vacuum, oil from the glass is sucked through the suction pipe. The oil comes drop by drop through a droplet into the air stream, which disperses the droplets into the oil mist and carries it to the lubrication sites. The principle of operation of the oiler and the components are shown in Figure 30.

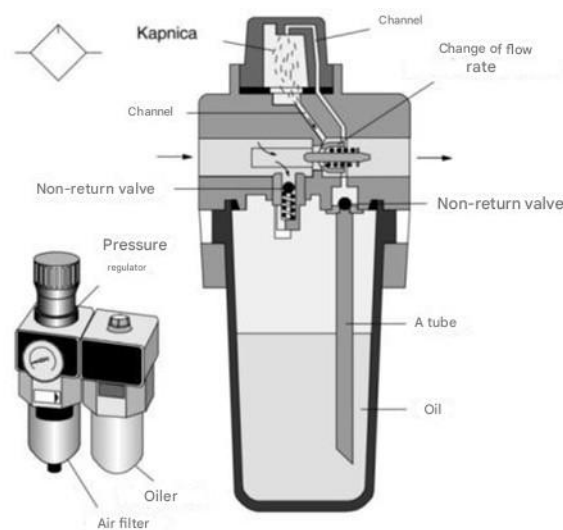


Figure 30: Oiler
Source: Croser and Ebel, 1994

It is recommended to dose 1 to 10 drops of oil per cubic meter of compressed air. The correct dosage can be tested: at the farthest valve, remove the inlet pipe and direct it towards a piece of white cardboard about 20 cm away. Even after a long time, there should be no noticeable oil drops on the cardboard, only a pale yellow stain.

The problem with the maintenance of the oiled air system arises due to oil deposits on the inner walls of the supply pipes. Such contaminated pipes are very difficult to clean. Oil deposits can also cause hardening of components; especially when idle for a long time. After a



weekend or holiday, it may happen that the oiled components will not work properly (gaskets stick to the seat). So the basic rule applies: compressed air should be prepared unooled.

The elements described above can also be represented by the symbols shown in Figure 31. Symbols do not show the design properties of individual elements, but the principle of operation.

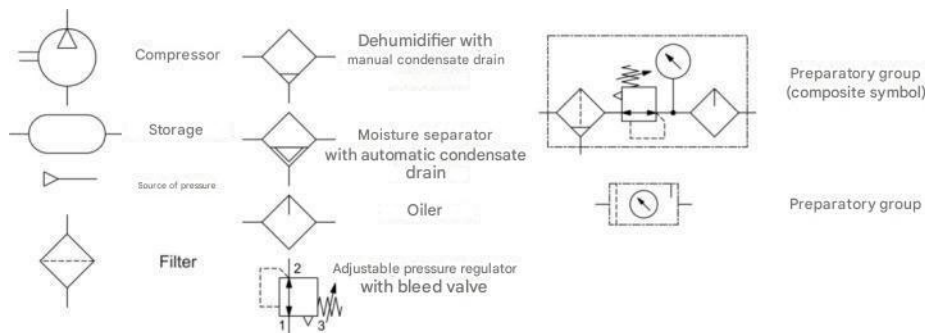


Figure 31: Display of air conditioning elements with symbols
Source: Croser and Ebel, 1994

SUMMARY

To prepare compressed air, we use ambient air, which is sucked in with a compressor and pressurized through the pipeline network. The ambient air contains certain impurities, such as dust, moisture, soot, particulate matter and other impurities.

The prepared compressed air is brought to an individual extraction point or consumer through a network that is closed in a circle for a more stable supply of compressed air. When implementing the network, care must be taken to ensure that the cross-section of the pipeline is large enough so that air outlets are made on the upper side of the pipeline, thus preventing condensate from getting from the main line to the extraction point. Pipe laying should not be carried out in hard-to-reach places to check the tightness of the network. It is imperative to take into account the slope of the pipeline in the amount of 1% in the direction of the air flow and to predict the discharge of condensate at the lowest point.

A pressure drop occurs in the pipeline network due to the length of the pipeline network and various compressors, which can lead to disruption in the operation of individual devices. Therefore, at each sampling point, we use a preparation group consisting of a pressure regulator with a built-in filter, but also an oiler.



QUESTIONS AND TASKS

1. Explain what factors we need to pay attention to when choosing an air drying method.
2. Explain how the built-in elements (arches, latches ...) affect the determination of the clear diameter of the pipe.
3. Based on the data and with the help of a nomogram to determine the clear diameter of the pipe and a nomogram to determine the alternate length of the pipe, determine the clear diameter of the pipe. **Air consumption:**

Current air consumption	= 1200.0 m ³ /h
Projected increase in spending = 50%	= 500.0 m ³ /h
Projected losses = 10%	= 150.0 m ³ /h

Total consumption = 1,850.0 m³/h

Other information:

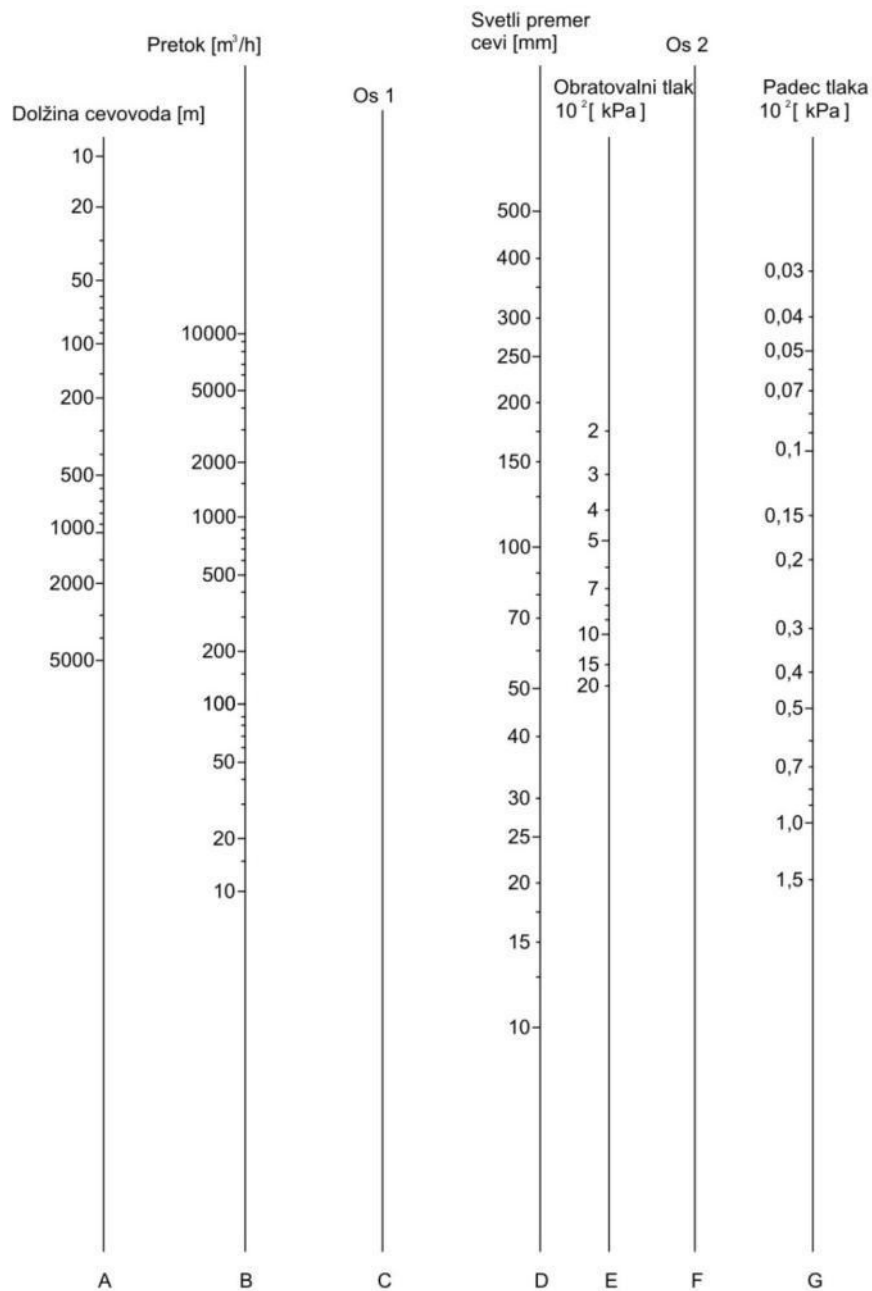
Operating pressure	= 800.0 kPa
Allowable pressure drop= 10.0 kPa	
Length of the pipeline	= 650 m

Which damping elements are installed in the pipeline and how many are shown in Table 6 below.

Table 6: Damping elements

Element	Number of pieces	Alternate length	Total alternate length
Normal arc (90°)	24 pieces	24 x ___ m m
T – basket	30 pieces	30 x ___ m m
Latch	15 pieces	15 x ___ m m
Flow valve	10 pieces	10 x ___ m m
		Together m
		Clear Diameter Pipeline Mm





- The company has organized two-shift work. In production, they have an operating pressure set to 6 bar. Somewhere in the pipeline network, air leaks due to poor execution of the joint between the network pipe and the valve. This leak corresponds to an opening diameter of 2 mm. Use the diagram to determine the lost amount of air in [m³/min] and calculate the daily air loss.



1.4. PNEUMATIC WORKING (EXECUTIVE) COMPONENTS

Pneumatic working components are devices that convert the energy of compressed air into a straight line or rotational motion. A one-way and two-way cylinder form the basis for a variety of further design variants.

Linear and rotational movements can be carried out easily and inexpensively with pneumatic working components. The designs of individual elements vary from manufacturer to manufacturer. For control, it is important to know the function of the pneumatic component and to be able to calculate it according to the requirements and then select it from the catalog.

1.4.1. PNEUMATIC COMPONENTS FOR LINEAR MOTION

Pneumatic cylinders convert the energy of compressed air into a straightforward movement of the piston. The movement of the piston is divided into forward or working movement and reverse movement or return movement. Depending on this, the cylinders are divided into unidirectional, in which the compressed air performs only the working movement, and two-directional, where the compressed air performs the working and return movement. Piston cylinders are most often used, but unidirectional cylinders can also be diaphragm.

In the case of a unidirectional cylinder, compressed air is supplied from one side only. He can only do the work in one direction. In unidirectional cylinders with a built-in return spring, the length of movement is limited due to the design possibilities of installing the spring. The spring must be dimensioned in such a way as to return the piston to its initial position at a sufficiently high speed. An example of a DC cylinder is shown in Figure 32.

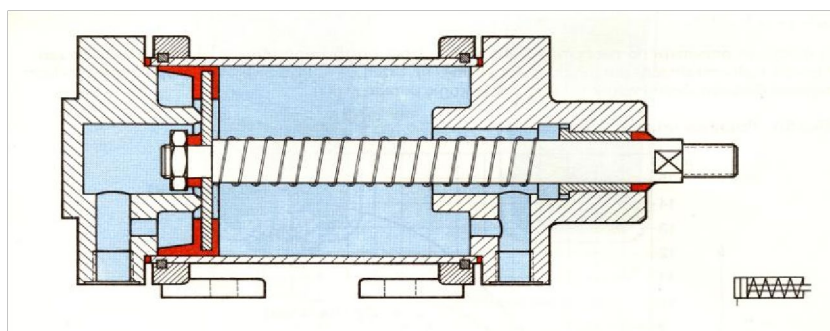
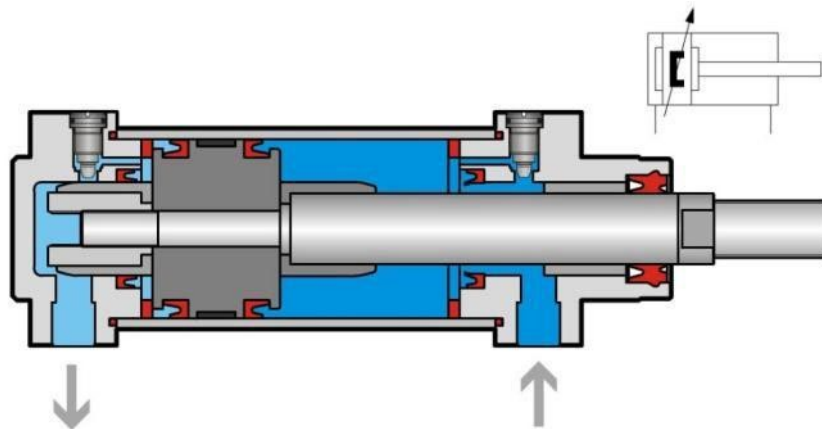


Figure 32: DC Acting Cylinder
Source: Croser and Ebel, 1994

In unidirectional cylinders with a built-in return spring, the length of movement is limited due to the design possibilities of installing the spring. For this reason, DC cylinders with a movement of no more than 80-100 mm are produced. Depending on the design, DC cylinders are used for various functions: feeding, distributing, collecting, assigning, clamping, broadcasting.



A two-way cylinder is similar in design to a one-way cylinder, but it is without a return spring. It has two working connections through which pressure can be applied alternately from one side or the other of the piston. Due to this, the two-way cylinder can perform work in both directions of movement and is thus useful in many cases. The force transmitted to the piston rod is slightly higher when moving forward than when moving backwards due to the different sizes of the piston free surfaces.



*Figure 33: Two-way cylinder with final damping and permanent magnet
Source: Croser and Ebel, 1994*

If a larger mass is moving, a two-way cylinder with final damping is used. This prevents the piston from hitting and damaging the cylinder. Shortly before the final position, an additional piston closes the unobstructed venting of the cylinder. Air can then only escape through an adjustable throttle and the piston moves to its final position at a reduced speed. The throttle should not be completely closed, otherwise the piston cannot move to its final position. In Figure 33, we can see that the piston has a permanent magnet built into it, which serves to control the position of the piston.

The cylinder consists of a casing tube, a rear and bearing cover, a piston with a gasket (double cylindrical cuff), a piston, a bearing bushing, a sealing ring, connecting links and gaskets. A predominantly seamless, trailed steel tube is used for the casing tube.

To extend the service life of the piston seal, the inner sliding surface of the hose is finely machined (honed). For special purposes, a tube made of aluminum, brass or steel with a hard chrome sliding surface is used. These special versions are used for less frequent use of rollers or in cases of corrosion effects.

For the rear and bearing covers, predominantly cast iron (aluminum, malleable cast iron) is used. Fastening of the cover and bottom to the casing tube is carried out with clamping screws, thread or flanges.

The piston is made of improved steel. The threads of the piston are rolled to reduce the notching effect.



The **linear drive** shown in Figures 34 and 35 consists of a cylindrical tube, a piston and an external slide. The piston moves freely in a cylindrical tube under the influence of compressed air. A permanent magnet is built into the piston and slider. The movement of the piston is transmitted to the slider by magnetic forces. Just as the piston moves under the influence of compressed air, so does the slider (synchronously). These cylinders are used for particularly long movements; even up to 10 m. The device being moved can be attached directly to the slider.

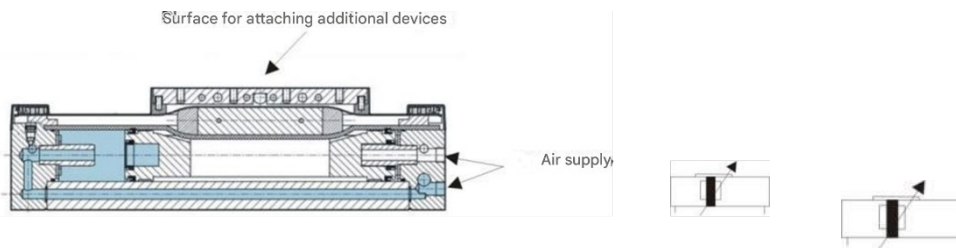


Figure 34: Linear drive

Source: http://pdf.directindustry.com/pdf/festo/dgp-Linear-Drive-unit/4735-24720_13.html

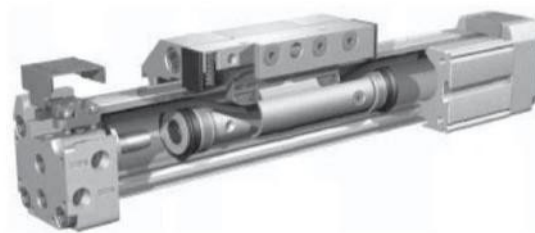


Figure 35: Linear drive

Source: http://pdf.directindustry.com/pdf/festo/dgp-Linear-Drive-unit/4735-24720_6.html

Pneumatic components for linear motion can also be illustrated by the symbols shown in Figure 36.

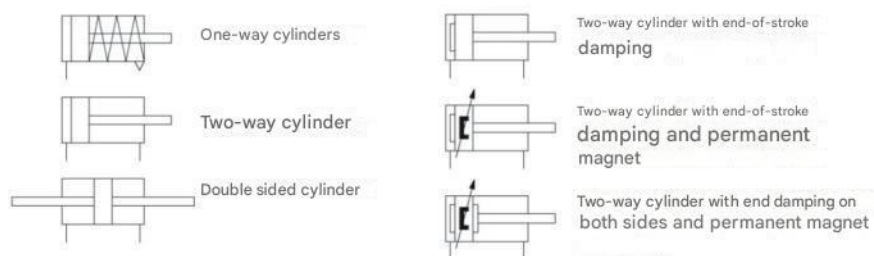


Figure 36: Symbols of pneumatic components for linear motion

Source: Haring, Metzger, and Weber, 2009



1.4.2. PNEUMATIC COMPONENTS FOR ROTATIONAL MOTION

The **retractable cylinder** has the end of the piston at a certain length serrated, shown in Figure 37. When the piston moves, the piston drives the gear and thus a rotational motion is obtained from the straight line. Depending on the direction of movement of the piston, the gear rotates in one direction or another. The angle of rotation depends on the execution; from 45°, 90°, 180°, 290° to 720°. There is also the ability to adjust the rotation depending on the maximum area.

The torque depends on the air pressure, the piston surface and the gear ratio. The swivel cylinder can be used for turning workpieces, for bending metal pipes, for regulating air conditioning and the like. The twisting cylinder in cross-section is represented by Figure 38.

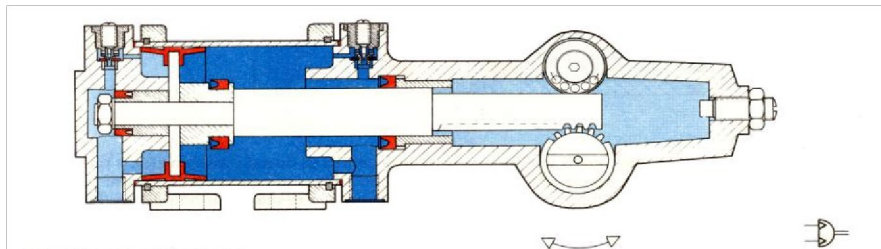


Figure 37: Swinging cylinder
Source: Croser and Ebel, 1994

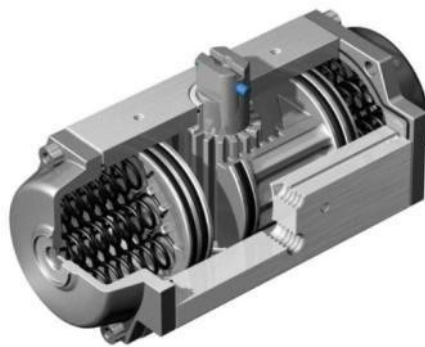


Figure 38: Swivel cylinder
Source: Haring, Metzger, & Weber, 2009

The **pivot wing cylinder** represented by Figure 39 has a limited angle of rotation. The angle of rotation is rarely greater than 300°. The problem is the sealing and dimensional volume. With it, we achieve practically only small torques. They are occasionally used in pneumatics, and often in hydraulics.



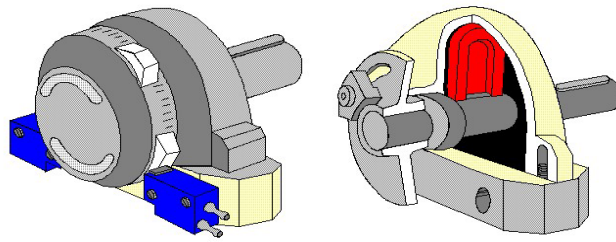


Figure 39: Swivel wing cylinder
Source: Croser and Ebel, 1994

For a simplified representation of the swivel cylinders, the symbols shown in Figure 40 are used.

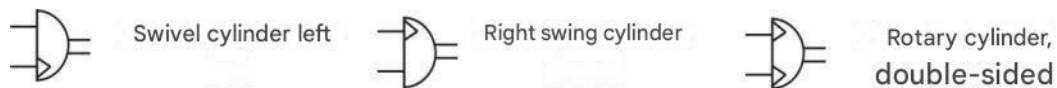


Figure 40: Symbols of pneumatic components for rotational motion
Source: Croser and Ebel, 1994

1.4.3. PNEUMATIC MOTORS

Pneumatic motors are devices that convert pneumatic energy into mechanical rotational energy. Predominantly, in practice, we use pneumatic motors - without a limited angle of rotation.

Pneumatic motors are divided according to their construction into:

- piston engines
- vane motors
- gear motors
- turbine engines.

Piston engines are divided by design into radial and axial. In radial engines, compressed air is driven by a crankshaft via radially mounted cylinders. For the sake of uniform running, several rollers are installed. The performance of the engine depends on the inlet pressure, the number of pistons, the area of the pistons, the length of the stroke and the speed of the pistons. The mode of operation of axial motors is similar to radial ones. With five longitudinally mounted rollers, the linear motion is changed into rotation by means of a braid. Due to the uniform torque and thus the smooth running of the engine, two cylinders are filled with compressed air at the same time.

These engines are made for both right and left direction of rotation. They reach a maximum speed of up to about 5000 rpm with a performance range of 1.5-19 kW (2-25 hp) at normal pressure.



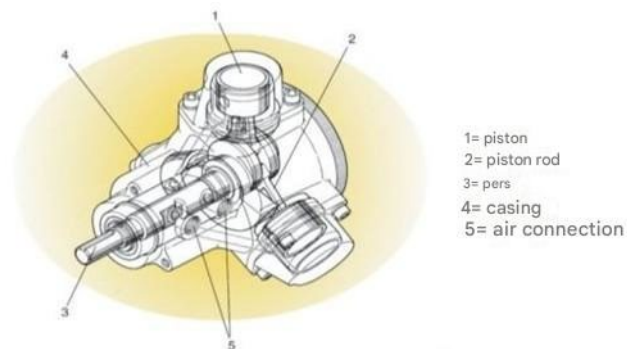


Figure 41: Radial motor

Source: http://www.guedon.de/fileadmin/user_upload/pdf/guedon-Radial-Kolbenmotoren-Reihe-p1v-p-p09pdf.pdf

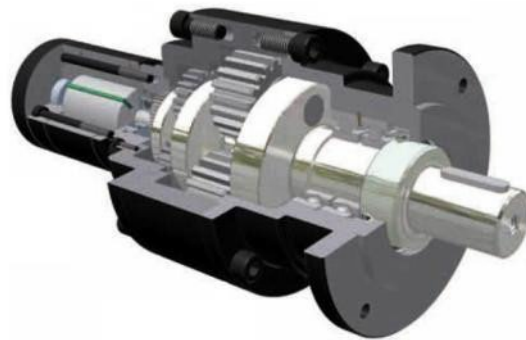


Figure 42: Vane motor

Source: http://www.guedon.de/fileadmin/user_upload/pdf/guedon-Robusta-Druckluft-motoren-Reihe-p1v-m-p09pdf.pdf

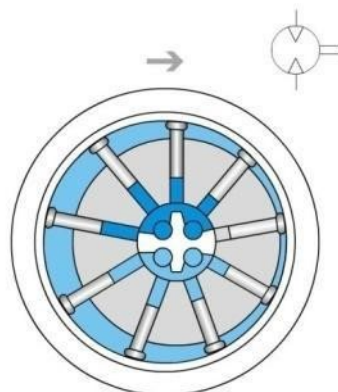


Figure 43: Vane motor

Source: Croser and Ebel, 1994

The vane motor has an eccentrically integrated rotor in the cylindrical housing. There are grooves in the rotor in which there are lamellas. When the rotor rotates, the fins are pressed against the wall of the cylindrical housing due to centrifugal force. This ensures a seal between the individual cells. The rotor speed is between 3000 and 8500 min^{-1} . Also, vane motors can



rotate to the right or left, the capacity ranges from 0.1-17 kW (0.1-24 hp). Lamellar motors are characterized by simple construction and low weight.

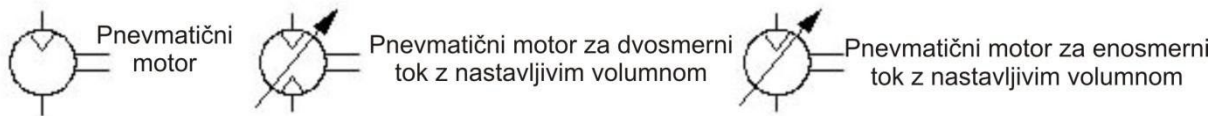


Figure 44: Symbols of pneumatic motors
Source: Croser and Ebel, 1994

1.4.4. METHODS OF ATTACHING CYLINDERS

The method of attaching the cylinder is shown in Figure 44 and depends on the installation of the cylinder on the machine. If no subsequent change of installation is provided, permanent fixing of the cylinder can be carried out. Otherwise, we fix the cylinders using additional elements so that they can be easily dismantled, installed differently or elsewhere.

It is necessary to adjust the attachment of the cylinder and the connection of the piston so that the cylinder is loaded only in the axial direction.

In case of improper adjustment, as well as in the case of excessive axle force, the following adverse effects occur:

- high local plate pressures in the cylinder bushing, resulting in rapid wear;
- high local flat pressures on the piston;
- increased and uneven loads on the piston and piston.

These loads significantly reduce the life of the cylinder. By using bearings that are adjustable three-dimensionally, harmful consequences can be eliminated.

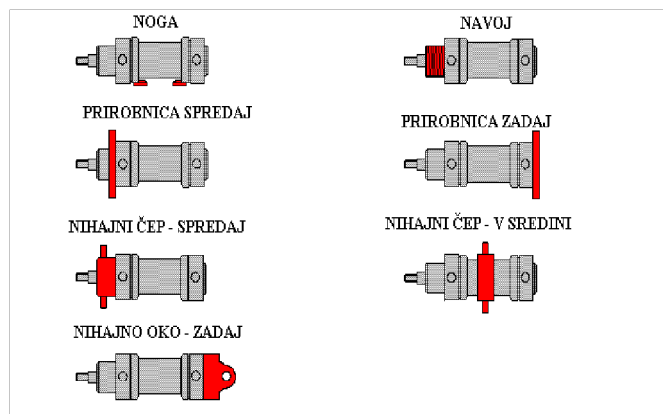


Figure 45: Methods of attaching cylinders
Source: Croser and Ebel, 1994



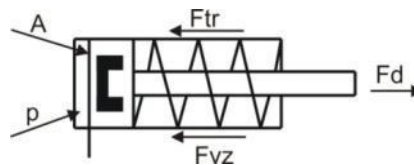
1.4.5. CYLINDER SIZING

The force of the piston of a pneumatic cylinder depends on the air pressure, the diameter of the cylinder and the friction of the sealing elements. The actual force at normal operating pressures (400-800 kPa) is less than the frictional force, which is usually 3-20% of the theoretical force. In the case of unidirectional cylinders, we must also take into account the force of the return spring.

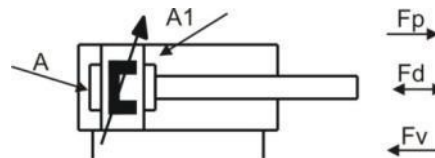
Piston force at DC cylinder:

$$F_{teor} = A \cdot p$$

$$F_d = A \cdot p - (F_{tr} + F_{vz})$$



Force at a two-way cylinder



$$F_d = A \cdot p - F_{tr}$$

$$F_d = A_1 \cdot p - F_{tr}$$

Actual pushing force

Actual pulling force

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

Area at piston working motion

$$A_1 = \frac{(D^2 - d^2) \cdot \pi}{4}$$

Piston retraction area

F_{teor} = theoretical force of the piston [N]

F_d = actual piston force [N]

F_{tr} = frictional force (3-20% F_d) [N]

F_{vz} = spring return force [N]

A = usable area of the piston [m²]

A_1 = area of the piston coil [m²]

D = diameter of the cylinder [m]

d = diameter of the piston [m]

p = working pressure [Pa, N/m²]



1.4.6. CALCULATION OF AIR CONSUMPTION

In order to ensure sufficient volumes of air, we need to know the consumption of pneumatic devices. The data on air consumption can also be used to calculate energy costs.

Air consumption = working pressure · pressure pressure ratio · of length · number of movements [min].

$$T_r = \frac{101,3 + \text{delovni tlak [kPa]}}{101,3}$$

p = working pressure

T_r = pressure ratio

Air consumption is faster and easier to determine according to the nomogram, where it is given for cm of movement of a certain cylinder diameter and for pressures from 200-1500 kPa (2-15 bar).

DC cylinder air consumption:
$$Q = s \cdot n \cdot \frac{D^2 \cdot \pi}{4} T_r [l / \text{min}]$$

Air consumption for a bidirectional cylir
$$Q = s \cdot \left[\frac{D^2 \cdot \pi}{4} + \frac{(D^2 - d^2) \cdot \pi}{4} \right] \cdot n \cdot T_r [l / \text{min}]$$

Q = amount of air [l/min]
 s = length of movement [cm]
 n = number of movements [min]
 D = piston diameter [cm]

Air consumption can also be determined on the basis of the nomogram in Figure 70, where we have to take into account the equation for a unidirectional or bidirectional cylinder.

Air consumption according to the nomogram for a DC cylinder: $Q = s \cdot n \cdot q [l / \text{min}]$

Q = amount of air [l/min]
 s = length of movement [cm]
 n = number of movements [l/min]
 q = air cons. per cm of movement [l/cm]



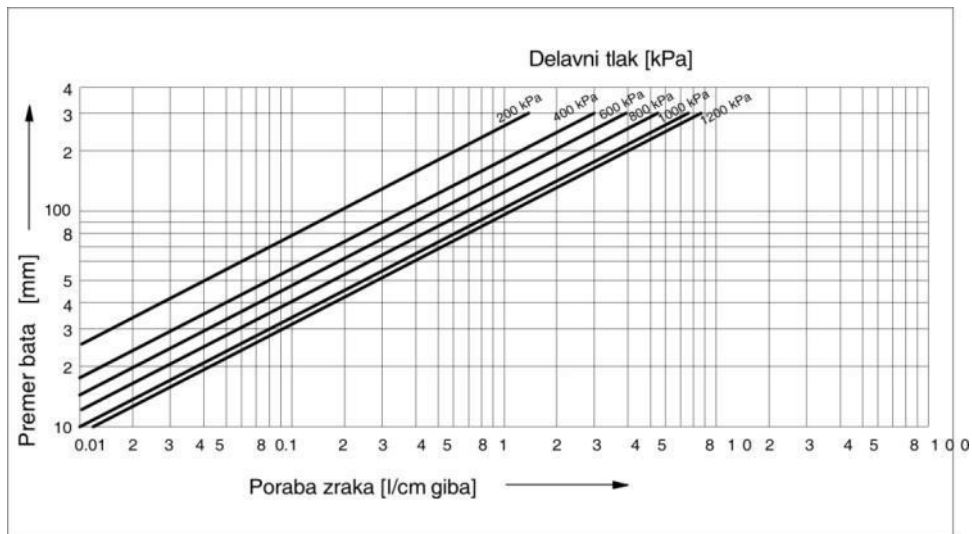


Figure 46: Nomogram to determine air consumption
Source: Croser and Ebel, 1994

Taking into account the above data, we get:

$$Q = 2 \cdot \left(10 \text{ cm} \cdot \frac{10}{\text{min}} \cdot \frac{0,134 \text{ l}}{\text{cm}} \right) = 26,8 \text{ [l/min]}$$

The calculated amount of air consumption is increased from 10% to 20%, depending on the design of a particular cylinder, since it is necessary to take into account the dead spaces that are filled with each movement of the cylinder.

SUMMARY

Pneumatic working components for straight-line motion are rollers with which we perform pushing, and in certain cases also pulling. Manufacturers of pneumatic cylinders indicate in their catalogues the specific air consumption q . With it, they indicate the air consumption in liters per centimeter of piston movement. The main areas of application are pushing, lifting and clamping of workpieces.

To perform rotational movements, we use rotary drives and motors. The angle of rotation depends on the individual design and is usually infinitely adjustable.



QUESTIONS AND TASKS

1. Based on the data, calculate the actual force of the two-way cylinder when pushing and pulling.
D = 50 mm
d = 12 mm
p = 600 kPa
A = 19.625 cm²
A₁ = 18.5 cm²
F_{tr} = 10% of the mean value
2. What is the air consumption of a bidirectional cylinder with a piston diameter of 50 mm and a piston diameter of 12 mm, with a stroke length of 100 mm, if the cylinder performs 10 movements per minute at a pressure of 600 kPa?
3. Explain what the air consumption of the connected working elements depends on?



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4. ANNEX



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